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Atlas of EEG, Seizure Semiology, and Management

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Introduction to EEG

Chapter: Introduction to EEG
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Electroencephalography (EEG) is an invaluable tool for evaluating patients for suspected seizures and encephalopathy. While the study of EEG itself can be exhaustive, as clinicians, we need to keep EEG in its supportive role. As such, the study of EEG must necessarily be performed on a solid foundation of clinical neurology and basic neuroscience.

Seizures and Epilepsy

Definitions

This is not a comprehensive glossary, as found elsewhere, but rather a summary of the important terms for classification and definition of seizures (see Table 1-1).

Table 1-1 Select Definitions

Term	***Definition***
Seizure	Sudden attack that is usually due to abnormal rhythmic discharge of neurons.
Epilepsy	Recurrent episodes of seizure activity typically associated with abnormal EEG rhythms.
Semiology	Study of signs of seizures.
Prodrome	Change in mood or cognition prior to a seizure, but which is not part of the seizure discharge.
Aura	Subjective sensation that precedes a seizure.
Ictal discharge	EEG discharge that is associated with a seizure.
Interictal discharge	EEG discharge that is seen in patients with seizures, yet the discharge is not itself a seizure.
Postictal period	Episode of altered consciousness or cognition following a seizure.
A complete glossary is provided in the Appendix.	

The most critical distinction is between *seizure* and *epilepsy*. A seizure is a transient event that includes symptoms and/or signs of abnormal excessive hypersynchronous activity in the brain (Fisher et al., 2005), whereas epilepsy is a disorder in which the patient has recurrent unprovoked seizures. All patients with epilepsy have seizures, whereas not all patients who have had a seizure have epilepsy. Recurrent seizures due to severe hyponatremia do not quality as epilepsy, since severe hyponatremia is known to provoke seizures. The traditional definition of epilepsy is that it takes at least two unprovoked seizures for the definition. A recent proposal suggested that one unprovoked seizure is sufficient if there is also evidence of enduring seizure tendency such as epileptiform activity on the EEG (Fisher et al., 2005). This proposal has been controversial and the authors favor the definition that requires at least two seizures.

Classifications

Before discussing the types of seizures, an introduction to seizure symptoms and signs is appropriate.

Symptoms and Signs

- *Prodrome* is an abnormal sensation preceding the seizure in some patients, not associated with epileptiform discharge.
- *Aura* is a subjective sensation that can immediately precede a seizure. This represents the initial portion of the epileptiform discharge.
- *Clonic activity* is episodic muscle contraction associated with a seizure.
- *Tonic activity* is increased muscle tone during a seizure, resulting in stiffening.
- *Automatism* is a stereotyped movement that occurs as part of a seizure, such as lip smacking.
- *Postictal period* is an episode of altered consciousness or cognition following a seizure.

Classification of Seizures and Epilepsies

The 1981 international classification is still the most commonly used seizure classification. It based on both EEG and clinical features of seizures (Commission on Classification and Terminology, 1981). Classification of seizures (Table 1-2) has two broad categories based on the onset being partial or generalized. *Partial-onset seizures* begin with a discharge in a focus, although they then can spread to other parts of the brain. Seizures that are generalized at onset, termed *primary generalized*, start bilaterally in the brain. Generalized seizures may have some asymmetry, but that usually switches from side to side.

Table 1-2 Classification of Seizures

Major Classification	***Selected Seizure Types***
Generalized	*Absence*: Staring spells with decreased response, often associated with subtle automatisms, lasting a few seconds, and with no postictal period.
	Generalized tonic-clonic: Sudden loss of consciousness, tonic stiffening followed by clonic movements of the body and/or extremities. Postictal period subsequently.
	Atonic: Sudden loss of tone which can be subtle (such as dropping of head), or widespread resulting in fall.
	Myoclonic: Brief seizures, lasting a fraction of a second. May be very focal and subtle or widespread and severe.
	Tonic: Sudden loss of consciousness with tonic posturing. Usually in neurologically impaired individuals.
Partial	*Simple:* Focal neurologic symptoms which can vary widely depending on location of origin, but without disturbance of consciousness.
	Complex: Focal neurologic symptoms including disturbance of consciousness.
	Secondarily generalized partial onset: Partial seizure of either simple or complex type which then spreads to become a generalized seizure.

Partial seizures are further subdivided into simple partial and complex partial. *Simple partial seizures* do not disturb consciousness, whereas *complex partial seizures* disturb consciousness. Complex partial seizures were previously termed *psychomotor* because of the cognitive disturbance. Partial-onset seizures can spread to involve most of the brain, and this is termed *secondary generalized seizure*.

Other classification schemes have been suggested that could be helpful in specific circumstances. One proposed seizure classification that has been used in the presurgical evaluation of epilepsy is purely semiological, based solely on observed clinical features. This classification includes somatotopic distribution of the seizure manifestations and evolution of these manifestations over the course of the seizure (Lüders et al., 1998). This classification will not be used in this book.

The International League Against Epilepsy (ILAE) has classified epilepsy syndromes into types summarized in Table 1-3. The classification of epilepsies still has two major subdivisions, localization-related (partial or focal being accepted synonyms), and generalized. Most patients will have only partial-onset seizures or only generalized onset seizures, and be classified into one of these two categories. There is a small group of patients with epilepsy who have both partial-onset and generalized onset seizures. They are classified in a third category of epilepsies and syndromes undetermined as to whether they are focal or generalized. Also classified into that category are subjects who do not have enough evidence for the type of seizure onset.

Table 1-3 Classification of Epilepsies

Classification	***Types***
Localization related (focal or partial)	*Idiopathic (pure epilepsy not related to an underlying cause)*
	Symptomatic (known etiology)
	Cryptogenic (presumed to be symptomatic but cause is unknown)
Generalized	*Idiopathic*
	Cryptogenic
	Symptomatic – can be nonspecific etiology or a specific etiology.
Undetermined as to whether focal or generalized	*With both generalized and focal seizures.*
	Without unequivocal generalized or focal features.
Special syndromes	*Include situation-related seizures – febrile convulsions, isolated seizures or isolated status epilepticus, seizures only when there is an acute metabolic or toxic event.*

Adapted from the Commission on Classification and Terminology of the International League Against Epilepsy, 1989. Proposal for revised classification of epilepsies and epileptic syndromes. *Epilepsia* 30, 389–399.

The classifications of seizures and epilepsies are evolving. The most recent revision of the seizure classification proposed by the International League Against Epilepsy has maintained the major division of seizures based on onset being generalized or partial, but has recommended replacing the term "partial" with "focal". Focal seizures were acknowledged to originate within networks limited to one hemisphere, meaning that they could be widely distributed in one hemisphere and possibly originating in subcortical structures. Generalized seizures were defined as "originating at some point within, and rapidly engaging, bilaterally distributed networks," which do not necessarily include the entire cortex (Berg et al., 2010a,b).

Not included in this classification are non-epileptic seizures previously termed *pseudoseizures*. A major task of the clinician and EEG-reader is the differentiation of epilepsy from non-epileptic events such as psychogenic non-epileptic seizures, cardiac arrhythmia, vasovagal syncope, orthostatic hypotension, transient ischemic attacks (TIA), and other conditions. This is discussed in depth in Chapter 6.

Semiology

Semiology is a non-medical term meaning the study of signs and symbols, which in our context means the symptoms and signs of seizures. The semiology of seizures of different localizations is discussed in detail in Chapter 5. A brief summary is provided in Tables 1-4 and 1-5.

Table 1-4 Semiology of Generalized Seizures

Seizure Type	***Features***
Absence	Staring spells.Automatisms that may be simple.Loss of awareness.Brief, usually less than 15 seconds.Occasional motor manifestations.
Tonic-clonic	Sudden loss of consciousness.Generalized tonic and/or clonic movements.
Myoclonic	Brief jerks that are variable in intensity, from small twitch to a massive jerk.Usually bilateral but may be unilateral.Often occur in clusters.No disturbance of consciousness.
Atypical absence	Loss of awareness.Slower recovery than with absence.Differentiated from absence mainly by EEG appearance.

Table 1-5 Semiology of Partial Seizures

Seizure Type	***Features***
Temporal	90% have aura.Most common aura is epigastric.Motor arrest, or Motionless staring, or Automatisms that may be oro-alimentary or extremity.
Frontal	Aura is uncommon. May be epigastric sensation. Focal clonic or tonic-clonic seizures.
Parietal	Sensory aura, which may have march. Can also have vertigo or focal weakness. Staring, or Tonic posturing, or Focal clonic activity, or Head and eye deviation, or Immobility.
Occipital	Elementary visual aura, or Visual hallucination. Blinking, and/or Ictal blindness.

Semiology in these tables refers to primary generalized seizures (Table 1-4) and partial-onset seizures without generalization (Table 1-5). Partial-onset seizures with secondary generalization are more complex and are discussed in Chapter 5.

Role of EEG in Diagnosis and Management

Routine EEG

Routine EEG is commonly performed in patients with episodic disorders in whom the differential diagnosis includes seizures and in selected patients with encephalopathy.

Valid indications for EEG include:

- Seizure or possible seizure;
- Well-controlled epilepsy to evaluate risk of recurrence upon withdrawal of treatment
- Syncope without definite cardiac or vascular cause;
- Loss of consciousness;
- Dementia when prion or virus is considered as an etiology;
- Encephalopathy without definite explanation;
- Coma.

Not valid indications for EEG include:

- Headache;
- Chronic behavioral disorder;
- Dizziness or vertigo;

While the majority of patients who have EEGs performed have suspected seizures, we will occasionally see patients in whom the documented reason for referral is dizziness or headache. Unless there is more to the story, these are inappropriate reasons for performing an EEG.

On the other hand, some epileptic syndromes are likely under-diagnosed. Non-convulsive seizures, including non-convulsive status epilepticus, may be incorrectly assumed to be metabolic encephalopathy, drug intoxication, or critical illness encephalopathy. Similarly, episodic focal deficits may be assumed to be transient ischemic attacks (TIA) yet are ultimately diagnosed as partial seizures. In these patients a positive motor component may be subtle or the history merely incomplete.

EEG-Video Monitoring

EEG-video monitoring refers to prolonged EEG with simultaneous video recording, intended to capture clinical events. It allows the correlation of brain electrical activity with clinical manifestations. *It is performed most commonly for the following indications:*

- Differentiation of epileptic seizures from non-epileptic seizures;

- Classification of seizure type to assist treatment.
- Localization of the epileptogenic zone in the presurgical evaluation of patients with drug-resistant seizures;

Less common indications for video EEG include:

- Quantification of seizures, particularly when seizures are very frequent and often missed by the patient.
- Quantification of response to treatment.
- Studying seizure precipitants particularly in reflex epilepsy.
- Documentation of ictal and interictal discharges during circadian rhythms.
- Evaluating the clinical correlate of EEG discharges which are unclear as to whether they are ictal or interictal.

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Basic Science of EEG

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Physiology

Discussion of the physiology of EEG begins with the foundations of neuronal function on a cellular level.

Membrane Theory

Neuronal membranes are composed of lipid bilayers that have transmembrane proteins. These proteins form the channels through which ions have differential permeability. Generally, potassium is sequestered inside the cell, whereas sodium is excluded from the cell. At rest, there is a greater permeability to potassium than other ions. During an action potential, there is greater permeability to sodium. The sodium-potassium pump uses energy to maintain the ionic gradients, which are so important for intact neuronal functions. This basic physiology is key to generation of EEG activity.

While the earliest membranes in evolution were likely composed of protein, membranes in all tissues now are composed of lipid bilayers (see Figure **2-1**). The lipid bilayer is composed of long sheets of phospholipids—substances with a hydrophilic end containing a phosphate group and chains of hydrophobic lipid molecules. Because of the aqueous polarity, the stable configuration is for the hydrophobic ends to be together in the interior of the membrane with the hydrophilic groups on the exterior of the membrane, on the inner and outer surfaces of the cells.

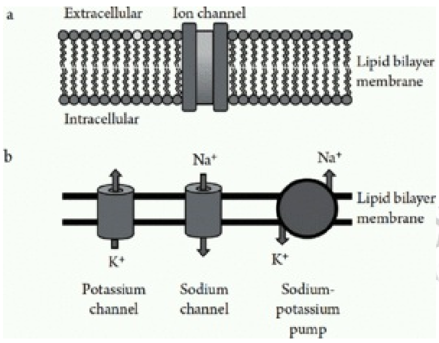

Figure 2-1:

a: Lipid bilayer membrane is impermeable to ions, but the ion channels allow for and control ion flow.

b: Simplified diagram showing differential permeabilities of the sodium and potassium channels and the sodium-potassium pump, which maintains the chemical gradient required for resting and action potentials.

Complex proteins are inserted in and through the membranes for a variety of functions, but the membrane components of greatest importance to us are the ion channels and ion pumps. Normally, the hydrophilic/hydrophobic arrangement of the membrane would make movement of many molecules across the membrane almost impossible, but with ion channels, the movements of both cations (positively charged ions) and anions (negatively charged ions) can be allowed and controlled.

Depending on the ion channel, conductance can be dependent on membrane potential. For example, some channels open only when a particular membrane potential is reached (*voltage gated*). At rest the conductance can be very low. When channels open, they often are open only for a short and specific time, so that even if the membrane potential remains at a level that would activate the channels, they close after a specified time (*open time*). Time sensitivity for channel closure is particularly important for allowing the membrane to be repolarized after a period of depolarization.

The sodium-potassium pump uses energy to maintain the ionic gradients, which are responsible for the diffusion potential and action potentials, pulling potassium inside the cell while expelling sodium from the cell.

Diffusion Potential

The diffusion potential is established by efflux of potassium, which travels down its chemical gradient until the resulting electrical gradient opposes further efflux of ions. The potential difference at which there is electrochemical equilibrium is approximately 75 mV for most neurons, with the inside negative.

The diffusion potential is essential for generation of the depolarization, which will occur with electrotonic conduction and action potentials.

Electrotonic Conduction

Depolarization of a segment of membrane results in activation of sodium channels. These allow the influx of sodium down its electrical and chemical gradient. The influx continues until the channel closes in a time-dependent manner. After the channel is closed, it cannot be opened until a fixed period has elapsed (i.e., the refractory period).

Depolarization of one segment of membrane results in depolarization of adjacent membrane by *electrotonic conduction* (see Figure **2-2**). The depolarization spreads but decays along the length of the membrane. If the electrotonic depolarization of the membrane is sufficient, an action potential can develop at a locus distant from the region of primary depolarization.

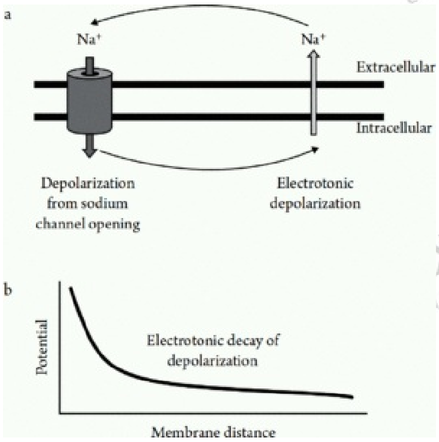

Figure 2-2:

a: Lipid bilayer membrane with sodium channel that is opened, resulting in depolarization not only at that site but downstream by electrotonic conduction.

b: Graph of exponential decay in depolarization as a function of distance.

Summation

Summation of potentials is essential for central neural transmission. Often the depolarization associated with a single synaptic event does not cause the release of sufficient transmitter to activate the subsequent neuron. Therefore, the potential changes produced by multiple incoming synaptic events are summed so that depolarization of the next-order neuron can reach threshold.

Spatial summation is where potentials developing on different parts of the neuron sum to produce a larger depolarization, more likely to activate the next-order neuron.

Temporal summation is where repetitive activation of a single input results in additive potential sufficient to activate the next-order neuron. The first potential has not completely decayed when the next potential arrives. So there is summation of the depolarization from the second potential on the first. With temporal summation, more than two potentials are usually required. Also, for there to be summation, the frequency of the potentials must be high enough and the decay of potentials slow enough to allow for potential summation. The decay rate is dependent on *time constant*, which is a measure of how long it takes for potentials to decay across a membrane; a longer time constant results in longer duration of depolarizations. Time constant is dependent on a number of factors, but a major factor is membrane conductance.

Time Constant

Time constant is a term used both in membrane physiology and in basic electronics. In electronics, time constant describes the results of a step change in voltage input on an otherwise electrically stable system. This is discussed in detail later. In membrane physiology, time constant is a measure of the decay of potential change of an otherwise stable resting membrane potential.

For an RC circuit, or for a biological system modeled as such, the time constant is the time to achieve 1–1/*e* of the difference between the old and new applied voltages, where *e* is the natural logarithm base. Since *e* is approximately 2.7, the value of this formula is approximately 0.63 or 63%. So the time constant is the time to achieve approximately 63% of the difference between the new and old voltages..

The time constant is the product of the resistance and the capacitance across the membrane.

$TC = R \times C$

where TC is time constant, R is resistance to charge flow, and C is capacitance of the membrane.

The resistance is the inverse of conductance, where conductance is dependent on the number of ion channels that are open. The number of ion channels is dependent on a number of factors, including numbers of channels, current membrane potential, and time. Most channels open at certain potential and close after a certain time. More open channels and longer open times make for increased conductance, which by inverse is reduced resistance, which by formula is reduced time constant.

Postsynaptic Potentials

Postsynaptic potentials are created by the release of neurotransmitter onto the postsynaptic membrane. Transmitters modulate the conductance to ions on the postsynaptic membrane to produce their effects.

Excitatory transmitters such as acetylcholine and glutamate produce depolarization by opening of sodium and/or calcium channels. The depolarization can be recorded intracellularly as an excitatory postsynaptic potential (EPSP).

Inhibitory transmitters such as gamma- aminobutyric acid (GABA) produce opening of potassium and/or chloride channels which results in loss of excitability not so much by hyperpolarization of the membrane, but rather by clamping of the membrane potential near the equilibrium potential for these ions, which is far from threshold. For example, the depolarization that would normally be produced by the opening of sodium channels is blunted by the action of inhibitory transmitters essentially locking the membrane potential near the equilibrium potential for potassium. The potential produced is the inhibitory postsynaptic potential (IPSP).

Action Potential

The action potential is due to regenerative opening of sodium channels. The channel opening results in depolarization of adjacent membrane, which then causes sodium channels in these areas to open, thereby perpetuating the depolarization. The channels close in a time-dependent fashion.

The difference between an action potential and an excitatory postsynaptic potential is that with an action potential the opening of the sodium channels results in further depolarization and thereby further opening of more sodium channels, as a regenerative cycle (see Figure **2-3**). The process is regenerative until terminated by time and changing conductance to not only sodium but also other ions (e.g., potassium and calcium)

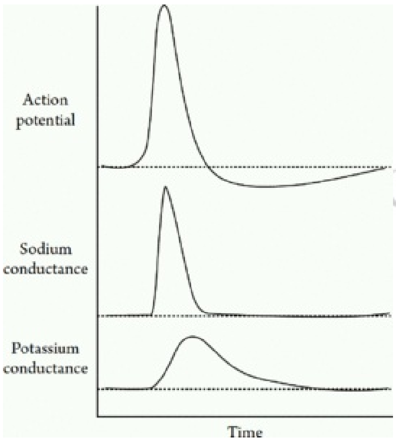

Figure 2-3:

Sequence of changes in membrane conductance associated with an action potential. Potassium conductance predominates during rest. Sodium conduction predominates during the action potential.

Electronics

Basic science of electronics is important not only for an understanding of how neurophysiological equipment works, but also for understanding how the patient becomes an integral part of the circuitry. This understanding can help to minimize artifact and improve the quality of studies.

The conceptual parallel between electrical circuits and biologic circuits is of more than passing interest to neurophysiologists. The general physical properties of current flow in biologic tissues are comparable to those in electrical devices, although the devices are far different. We will highlight some of these parallels when appropriate.

Circuit Elements

The circuit elements are combined with conductors to form complex circuits. Electronics has evolved from tubes and solder to circuit boards at a microscopic level. Traditional circuitry used boards to hold the elements and wires to connect them. The next development was the printed circuit board, where there were strips of conductor painted onto the board to aid connecting elements. Current design usually involves layers of conducting, semi-conducting, and non-conducting materials that are etched to form transistors, capacitors, resistors, and conductors (see Table 2-1).

Table 2-1 Circuit Elements

Element	*Features*
Conductor	Material that easily conducts current by allowing the flow of electrons.This requires atomic structure conducive to mobilization of electrons.
Non-conductor	Material that does not conduct current.
Semiconductor	Material that conducts better than a non-conductor but less well than a conductor. Used to make diodes and transistors.
Power supply	Source for power that imparts energy to electrons, thereby causing them to move.
Resistor	Element that opposes the flow of electrons, dissipating energy as heat.
Capacitor	Element that stores energy in the form of separation of charge.
Inductor	Element that stores energy in the form of magnetic field.
Diode	Device made by layering two pieces of semiconductor. Conducts in only one direction.
Transistor	Device made by layering three pieces of semiconductor. Integral for amplifiers.
Amplifier	Device to amplify signals. Semiconductors are integral components of amplifiers.

Conductors and Non-conductors

Conductors are able to allow electrons to move because they have unpaired electrons in their outer electron orbitals. Some of these atoms can accept an "extra" electron, resulting in a net negative charge, but with atomic stability. The spot for this extra electron is a *hole*. Other atoms can more easily donate an unpaired electron, which results in a net positive charge but is also atomically stable, since every orbital is then full (Figure **2-4**). During the process of conduction, electrons move from hole to hole, driven by a potential gradient that is established by the power supply or biologic tissue (Figure **2-5**).

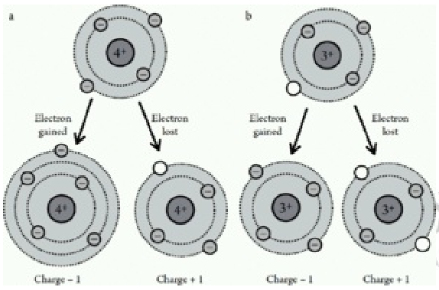

Figure 2-4:

Atomic structure of the outer orbitals of some important elements. A would be a non-conductor, B would be a conductor.

a: The atom is electrically neutral and all orbitals are filled, so it unable to easily donate or receive an electron. An electron donated to this atom would not be welcome, and formation of a new orbital does not occur. Losing an electron would require a large amount of energy and would not occur in an electronic circuit.

b: Electrically neutral but has one empty orbital spot. Can easily receive an electron. Gaining an electron is favored since it fills the outer orbital, even though there is electrical negative charge. Likewise, the single outer orbital electron can be donated easily.

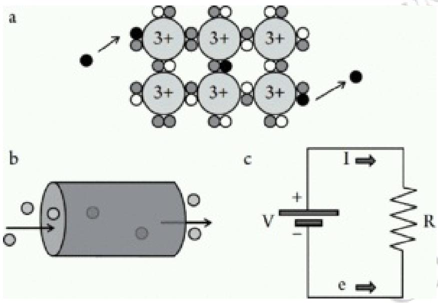

Figure 2-5:

a: Atomic structure of a conductor. Adjacent atoms share electrons, shown as small gray circles. The small white circles are "holes," which are unfilled portions of orbitals. Black circles represent the path of an electron through the conductor.

b: Less enlarged view of a conductor, showing electron flow through the conductor. By convention, current flow is defined as the flow of positive charge, therefore, in the opposite direction to the flow of electrons.

c: Simple circuit diagram of a conductor. The symbol for a battery "V" has the positive terminal upward. Electrons flow from the negative terminal (bottom) through the conductor

to the positive terminal. Current flow is opposite to the flow of electrons.

Non-conductors do not have unpaired electrons that can be donated or holes to accept electrons. Therefore, electrons cannot pass through non-conductors, unless there is such a large potential gradient across the material that electrons spark through the material. Contrary to some popular belief, sparking can occur through non-conductors.

Resistors

Resistors are composed of material that conducts less well than conductors, but in this circumstance dissipates some of the energy associated with the moving electrons as heat (see Figure **2-6**).

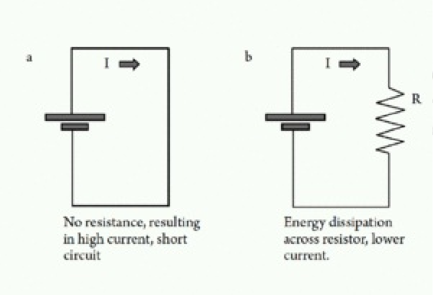

Figure 2-6:

a: A conductor connects the terminals of a battery. Current will flow from the positive terminal to the negative terminal through the conductor. Electrons are flowing in the opposite direction. The magnitude of current will quickly destroy the battery.

b: A resistor is inserted into the conductor circuit. This reduces the current flow by an amount that is proportional to the resistance of the resistor.

Resistors are discussed further in the next section, particularly regarding:

- Ohm's law;
- Summation of resistors in series;
- Summation of resistors in parallel.

Resistors are integral components of circuits since they regulate current flow. Insertion of resistors into a circuit reduces the rate of charge movement, or current. In addition to resistors as part of electronic circuits, biologic tissues have a resistance to charge flow.

When current flows through resistors, there is a *voltage drop* across the resistor which refers to the energy dissipated. Some resistors are purely designed for current regulation, whereas other circuit elements incorporate resistance as a mechanism to produce heat or light. For example, a modern incandescent bulb uses a high resistance filament to generate light, although only about 5% of the energy is dissipated as light, the rest is dissipated as heat.

Capacitors

Capacitors are composed of plates of conducting material separated by non-conducting material (see Figure **2-7**). Therefore, current cannot flow directly through a capacitor, although capacitive current can flow. Capacitive current is virtual current through the capacitor. The capacity or capacitance is a measure of the ability of the capacitor to store energy by separation of charge producing an electric field.

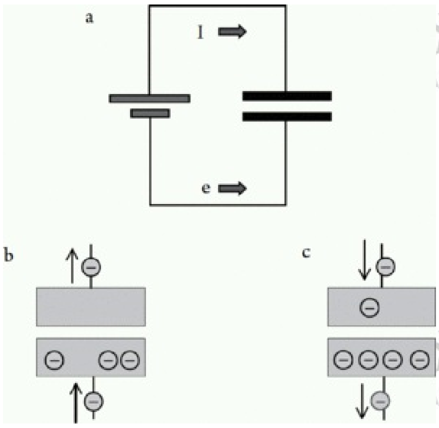

Figure 2-7:

a: Simple circuit of a battery charging a capacitor. When the battery is switched on, electrons flow from the negative terminal and onto the lower plate of the capacitor. Electrons leave the upper plate and travel through the conductor to the positive terminal of the battery. The departure of the electrons from the upper plate produces positive-charged holes.

b: Close-up of the capacitor during the charging phase. Electrons accumulate on the lower plate and depart from the upper plate.

c: When the battery is switched off while the terminals of the capacitor are connected, electrons flow off the lower plate and onto the upper plate. The motivation for the electron movement is the charge separation across the plates of the capacitor.

When the power supply is turned on, electrons flow and build up on one plate of the capacitor. Because of repulsive effect on electrons on the other plate, electrons stream off this plate to the positive end of the power supply, leaving a positive charge. Eventually, the potential developed across the capacitor is sufficient to oppose the flow of current, and net electron flow stops. At this point, the charge across the capacitor is equal and opposite to that of the power supply.

When the power supply is switched off, the only potential difference in the circuit is across the capacitor. Electrons flow from the negative-charged plate through the connecting conductor and onto the positive-charged plate, completing the circuit.

Capacitors alter the frequency response of electronic circuits and additionally are used for a variety of electronic applications requiring pulsed current—such as strobe lights and detonators. The former are used routinely in EEG labs, the latter are not.

Inductors

Inductors are simply a coil of conducting wire (see Figure **2-8**). They capitalize on the general property of conductors to build up a magnetic field around them when current flows. As electrons flow through a straight conductor, a weak magnetic field is created. This field is large enough to be detected by sensitive equipment but not typically enough to significantly influence the flow of current. However, when the conducting wire is coiled, the magnetic fields from multiple coils are summed, so the magnetic field can be substantial.

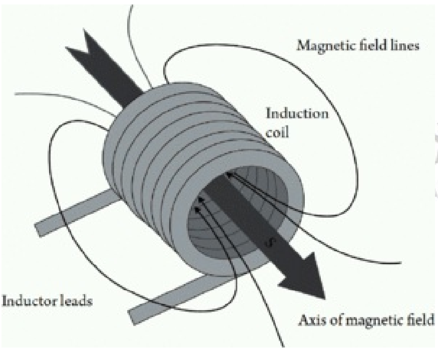

Figure 2-8:

Diagram of an inductor coil. The coil of wire results in the magnetic fields being in effectively the same direction, producing summation of the fields. This makes for a powerful field that is dependent on the amount of current flowing through the coiled wire and the number of turns of the coil.

One use of an inducting coil is as an electromagnet, where a constant current through the coil creates a stable magnetic field with north and south poles, just like a permanent magnet. If there is an iron core in the middle of the coil, then the magnetic field is even stronger. However, in the context of neurophysiological equipment, inductors are important for the effect this magnetic field has on the flowing current. Consider a power supply connected to an inductor (Figure **2-9**). When the power supply is switched on, current begins to flow but there is a delay in development of maximal current. As the magnetic field builds up, there is a lag in current until the field is maximally developed. At that point, the impedance abates and current freely flows. This is because the energy is taken from the system in creating the magnetic field.

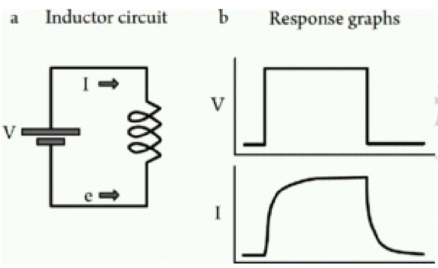

Figure 2-9:

a: Circuit diagram of a power supply (V), inductor, and current (I) flowing through the circuit. Electrons flowing through the inductor coil produce a magnetic field. b: Graph of the response to a step in voltage (V). The current builds up but more slowly than expected because some of the energy of the current flow is used to generate the magnetic field.

The energy stored in the magnetic field is reclaimed when the power supply is switched off. In this case, the current ceases to flow from the battery, and the magnetic field begins to collapse, but this collapse in magnetic field causes current to flow through the system, in the same direction as it initially did during the charging phase (see Figure **2-9**). The production of electric current by a changing magnetic field is *induction*.

Inductors are especially important for radios and a variety of equipment in which flow of current through a circuit needs to be controlled. But the biggest implication of inductors for neurophysiology purposes is *stray inductance*. This is unintentional inductance, due to the presence of wires all around us. While they may not have all of the turns and tight structure of a commercial inductor, they can produce sufficient inductance to cause stray current flow and thereby noise in our sensitive neurophysiologic equipment. If all current was direct current (DC), so there was little or no change in voltage, this would not be a huge issue, but since line power is alternating current (AC), by definition voltage is swinging from positive to negative and back at 50 or 60 Hz, depending on the frequency of oscillation of line power. This means that the constantly changing magnetic field is causing fluctuating current to be induced in conductors of your systems. This might be in the microvolt range, but this is more than enough to cause artifact in electrode leads that routinely measure these levels of electrical activity.

Semiconductors

Semiconductors are so called because they semi- conduct—they conduct better than non-conductors but less well than conductors. They are composed of a non-conducting material that has a few atoms of conducting material intermixed. The base material is usually silicon or germanium and the atoms inserted within the base material are often arsenic or gallium. This is *doping*, and the type of the intermixed material determines the type of semiconductor. Silicon and germanium have 4 outer electrons, making them essentially non-conductors (see Figure **2-10**). Arsenic has 5 outer electrons, so in a lattice with silicon, there is tight binding of 4 of these and 1 is “spare” in that it is not tightly bound and therefore can dissociate from its nucleus and move fairly easily through the material from arsenic atom to arsenic atom. This is an N-type semiconductor since it has

spare electrons from an orbital point of view though they are not spare in terms of electrical neutrality. The term *N-type* means that it resembles a negative material in that it is happy to donate a negative-charged electron. Doping a semiconductor with gallium, which has 3 outer electrons and therefore an unfilled electron orbital, creates a P-type semiconductor. The P-type indicates that the semiconductor has properties of a positive material in that it likes to accept an electron. This naming can be a little confusing in practice when N-type semiconductors develop a positive charge and P-type semiconductors develop a negative charge when these materials are joined as layers.

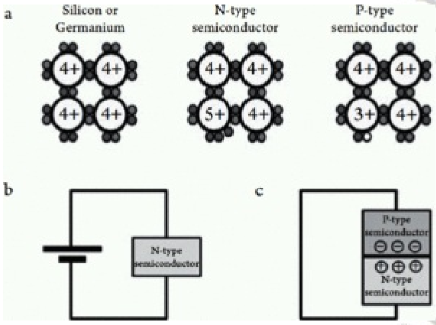

Figure 2-10:

a: Atomic structure of semiconductor material. Pure silicon (left) is a non-conductor. Doping of this material with a conducting element results in either available electrons for flow (center, N-type), or available empty electron orbitals, which can temporarily host a flowing electron (“hole” or P-type).

b: A piece of semiconductor material as part of a circuit can conduct electric current, though not as well as a conductor.

c: Two semiconductor pieces are placed together without a battery. Some of the spare electrons of the N-type semiconductor move to occupy partially filled orbitals of the P-type semiconductor. This is analogous to the diffusion potential of biological membranes.

Mechanisms of action of semiconductors are not crucial to understanding devices, but understanding the concepts is appropriate considering the widespread use of semiconductors in our lives.

Diodes

Diodes are composed of two wafers of semiconductor, which are then joined. When the two are placed together, electrons migrate from the N-side to the adjacent P-side, the electrons filling some of the available electron orbitals. This creates a junction potential, which develops to the point that the charge differential opposes the further flow of electrons. This is similar to the junction potential that develops across biological membranes. Therefore, at rest, the junction between these materials is polarized with a positive charge on the N-type side and a negative charge on the P-type side. (Figure **2-11**)

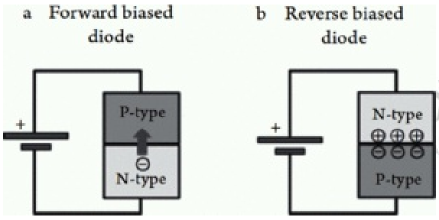

Figure 2-11:

a: A battery is connected to the N-P semiconductor complex. In this diagram, current can flow, since the junction potential between the two materials is negated by the applied voltage.

b: The position of the semiconductor materials is reversed so that the applied voltage serves to augment the junction potential. Current cannot flow. Since the N-P semiconductor junction allows for current flow in only one direction, this is a diode.

When a power supply is applied to deliver potential difference across the diode, current can flow in only one direction. If the negative side of the power supply is applied to the N-side, then the junction potential is negated so current can flow. On the other hand, if the polarity is reversed, electrons delivered to the P-side serve to augment the junction potential. There are no “extra” electrons or “holes” available to facilitate further current flow. Every atom on in the junction region has filled orbitals.

There are diodes in electrophysiological equipment, such as for rectifying AC voltage. However, the main purpose of semiconductors in our EEG equipment is for manufacture of transistors. The unidirectional conduction used for diodes is the foundation for transistor theory.

Transistors

Transistors are typically composed of three layers of semiconductors. One of the most common types is the junction bipolar transistor, shown in Figure **2-12**. With no applied voltage, junction potentials develop at the NP junctions. The left side of the circuit is the controlling side and the right side is the controlled side. The left side may be the biological voltage of the patient, and the right side is the rest of the amplifier circuitry.

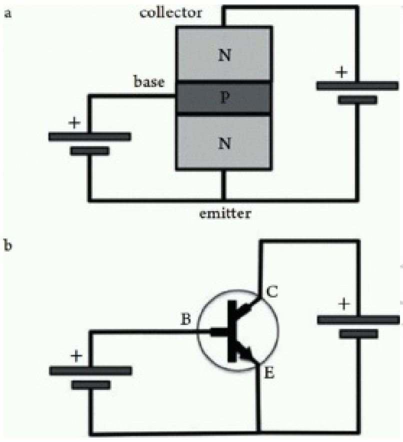

Figure 2-12:

a: A transistor is constructed from three layers of semiconductor material. Voltage supplied on the left side of the circuit controls the conductance across the entire transistor. Therefore, a small amount of voltage on the controlling side governs current flowing on the controlled side.

b: Circuit diagram of the transistor shown above.

The upper NP junction is reverse biased, and normally electrons would not flow. The lower PN junction is forward biased, and current can flow on the controlling side. When voltage is applied to the controlled side, this alters the potential developed at the upper PN junction, resulting in allowance of current flow. The voltage applied by the EEG machine's power supply to the controlled side is much larger than the voltage of the controlling side, so a small amount of voltage change in the controlling side alters the current flowing due to a much larger voltage on the controlled side. For most transistors of this type, the amplification is linear over a large range of input voltages, and the set amplification for each amplifier stage is about 9x.

Amplifiers are created by using transistors in series, to achieve the massive amplification needed to bring the electrophysiological signal into magnitude at which it can be used by the attached electrophysiological equipment.

Circuit Laws

Overview

The basic laws that govern electric circuits are many, but the most important are:

- Ohm's law;
- Kirchhoff's current law;
- Kirchhoff's voltage law.

In addition, there are a few basic additional formulae that are important to remember.

- Summation of resistors in series;
- Summation of resistors in parallel.

Table 2-2 presents a summary of these laws.

Table 2-2 Summary of Important Circuit Laws

Law	***Features***
Ohm's law	For a resistive circuit, the current flowing is equal to the applied voltage divided by the resistance. Or: $I = V/R$ Rearranged, this is $V = I \times R$ Where V is applied voltage, I is current, and R is resistance.
Kirchhoff's current law	For a node, or junction point of conductors, all of the current flowing into the node must equal the current flowing out of the node. Since outward flow can be considered the reverse of incoming, then: $\Sigma I_i = 0$ where I_i represents the individual currents.
Kirchhoff's voltage law	For a circuit loop, the sum of the voltage sources is equal to the voltage drops, where voltage drop is dissipation across a resistance. Or: $\Sigma V_S = \Sigma V_R$
Summation of resistors in series	For two or more resistors in series, the equivalent resistance is equal to the sum of the individual resistances. Or: $R_T = \Sigma R_i$ where R_T is total resistance and R_i is resistance of the individual resistors.
Summation of resistors in parallel	For two or more resistors in parallel, the reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistances. Or: $1/R_T = \Sigma (1/R_i)$

Ohm's Law

Ohm's law says that for any resistive circuit, the voltage is equal to the current times the resistance,

or:

$V = I \times R.$

This is one of the intuitive laws of electronics. As the voltage increases across a fixed resistance, the current flow increases. On the other hand, as the resistance increases with a fixed voltage, the current drops (see Figure **2-13**).

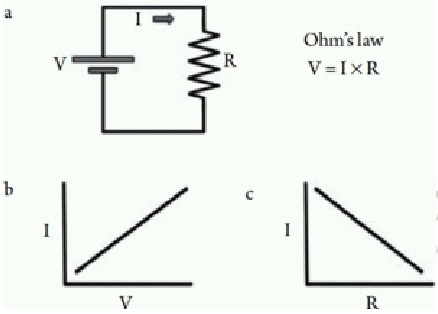

Figure 2-13:

a: Circuit diagram of a resistor-capacitor (RC) circuit. The power supply provides a voltage (V), which drives electrons around the circuit in the opposite direction to positive current (I) through the resistor (R).

b: Linear and positive relationship between applied voltage and current.

c: Linear and inverse relationship between resistance of the resistor and current flow. Higher resistance means less current.

Ohm's law is crucial for the development of other circuit laws and theories. Permutations of Ohm's law apply and are useful in circuit theory.

Current of a resistive circuit is equal to the voltage divided by the resistance, or:

$I = V/R$

Similarly, resistance in a resistive circuit is equal to the voltage divided by the current, or:

$R = V/I$

Kirchhoff's Current Law

Kirchhoff's current law is easy to conceptualize (see Figure **2-14**). The sum of the currents flowing into a node, or connector in a circuit, is zero. In other words, the sum of the current flowing into a node is equal to the sum of the current flowing out. This is evident since a connector point has no ability to store or modify energy.

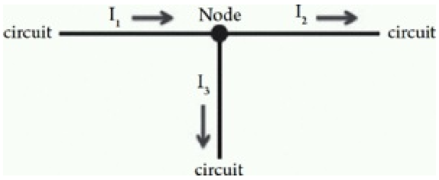

Figure 2-14:

The sum of the currents flowing into and out of a node is zero. The node cannot store or modify energy.

$\Sigma I_i = \Sigma I_o$

where I_i represents the incoming currents to the node and I_o represents the outgoing currents from the node.

This indicates that the sum of the incoming currents is equal to the outgoing currents. However, since outgoing currents are in the opposite direction from incoming currents, they can be considered negative currents, though this means negative from a mathematical point of view, not a charge point of view.

Therefore:

$\Sigma I_i = 0$

where I_i in this formula represents all of the individual currents.

Kirchhoff's Voltage Law

Kirchhoff's voltage law is somewhat more difficult to conceptualize (see Figure **2-15**). It says that for any circuit loop, the sum of the voltage sources is equal to the sum of the voltage drops. *Voltage drop* means dissipation of voltage across a circuit element, particularly in this case a resistor. Since voltage drops are of opposite direction to voltage sources, the law really says that the sum of the voltages around a circuit loop is zero.

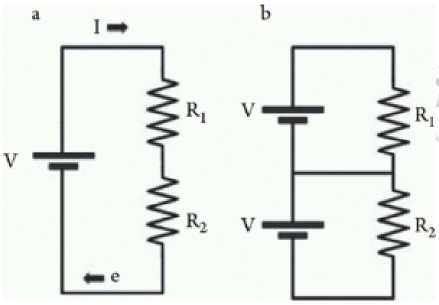

Figure 2-15:

a: The sum of the voltage sources and drops in a circuit loop is zero.

b: Kirchhoff's voltage law applies to all circuit loops, including each of the smaller loops in this diagram and the large loop encompassing both batteries and both resistors.

A *circuit loop* is any closed loop of connectors and their circuit elements. The figure shows both a simple single loop circuit and a more complex circuit with three loops—the three loops of the circuit on the right side of the image are, top, bottom, and the large loop encompassing both power supplies and resistors, without the central horizontal connector.

Kirchhoff's voltage law is derived in part from Ohm's law. The voltage drop across a resistor is proportional to the current and to the applied voltage, so as the voltage of the power supply is increased, current increases so the voltage drop across the resistor increases.

$\Sigma V_S = \Sigma V_R$

where V_S represents the individual voltage sources such as batteries or biologic signals, V_R is the voltage drop across each resistor.

Summation of Resistors in Series

Two or more resistors in series can be replaced conceptually with a single resistor with a total equivalent resistance (see Figure **2-16**). The intuitive assumption is that the total equivalent resistance is the sum of the individual resistances, and this is correct.

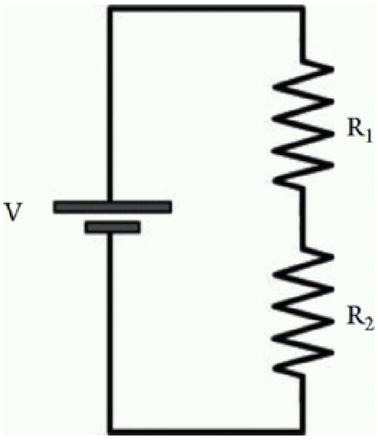

Figure 2-16:

The total resistance of two resistors in series is equal to the sum of the individual resistances.

Expressed mathematically:

$R_T = \Sigma R_i$

where R_T is the total equivalent resistance of the system, and R_i is the resistance of the individual resistors.

This seems intuitive because the energy associated with the electrons comprising the current is dissipated across multiple resistors, resulting in greater overall resistance.

Summation of Resistors in Parallel

Two or more resistors in parallel (see Figure **2-17**) can also be replaced conceptually by a single resistor with a total equivalent resistance. However, many find that the fact that the total resistance is less than the resistance of any of the resistors to be not intuitively obvious. This discrepancy is because although there may be two or more resistors, each resistor is a conduit for electron flow, so the more conduits in parallel, the lower overall resistance. An analogy would be a reservoir being emptied by one narrow tube. Adding additional tubes, no matter how narrow, reduces the overall resistance to flow. Each of these tubes can be considered to have a resistance—meaning how much they impede fluid flow—but the reciprocal of resistance is *conductance*—the capacity of the tube to allow flow.

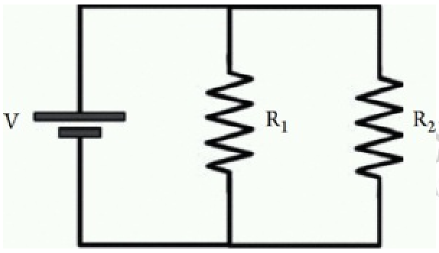

Figure 2-17:

The reciprocal of the total resistance of two resistors in parallel is equal to the sum of the reciprocals of the individual resistances.

Similarly, for electron flow, conductance is the reciprocal of resistance.

$G = 1/R$

where G is conductance and R is resistance.

The greater the resistance, the less the conductance. If there are two or more routes of conductance, then each route increases the overall conductance. The total conductance is equal to the sum of the individual conductances. Or:

$G_T = \Sigma G_i$

where G_T is the total conductance and G_i is the conductance of the individual resistors.

If we then substitute 1/R for the conductances, then we have the following formula:

$1/R_T = \Sigma (1/R_i)$

where R_T is the total equivalent resistance of the resistors in parallel, and R_i is the resistance of the individual resistors.

This is essentially how parallel resistances sum. The reciprocal of the equivalent resistance is equal to the sum of the reciprocals of the individual resistances.

Amplifiers

Overview

Amplifiers are integral to all modern neurophysiologic equipment. Biological potentials are of such small magnitude that amplification is required in order to handle and display the signals. The first stage of amplification is commonly at the head-stage of the device. This simple amplifier raises the magnitude of the signal so that it far exceeds the magnitude of electrical noise. Noise already in the electrode system will be amplified, however. Shielded cables then lead to the EEG machine, which is nowadays the combination of a computer and a display system. The EEG machine further amplifies the raw signal, which is then subject to either analog display or digital display.

Analog display consists of using the massively amplified signal voltage to drive pens on a paper display or to deflect an electron beam on a cathode ray tube. Digital display consists of analog-to-digital conversion followed by mathematical manipulations before digital video display and recording on some sort of digital storage media. Details of some of these steps are discussed below.

Amplifier Theory

Amplifiers do nothing other than increase the magnitude of an electric signal. When placed together in various arrangements, transistors can produce enhanced amplification or can alter the configuration of the signal.

Amplifier Circuits

Amplifier circuits have two ends, which can be termed *input* and *output*. Alternative names are *controlling* and *controlled.* The input side of the amplifier receives the biological signal. The output of the amplifier is the enhanced representation of the signal. This wording is chosen carefully, because it is not really just turning up the volume of the signal, but rather measuring the signal, then using a power source to drive the output to look like the input signal.

Amplifiers historically used tubes but currently use transistors as their device for controlling and multiplying signal. In either case, the device is a controlling device—the input signal controls passage of electricity through the unit.

Transistors

Transistors are the most important implementation of semiconductors. Almost all amplifiers use transistors as a foundation of amplification. Tubes are still used in some older equipment, but offer no significant advantages with many disadvantages.

The essentials of amplification with transistors was described above. The biological signal is applied to the controlling side and a higher-voltage representation of the signal emanates from the controlled side. Since the amplification needed for computer input is many orders of magnitude greater than most biologic signals, multiple stages are required for amplification. For purposes of discussion, each amplifier stage provides approximately 10x amplification so that a gain of 1000x requires 3 stages ($10 \times 10 \times 10 = 10^3 = 1000$). However, in reality, amplification is closer to 9x.

Single-ended versus Differential Amplifiers

Single-ended amplifiers are the elementary amplifying circuits created by the use of transistors (see Figure **2-18**). These consist of a transistor with the controlling side of the circuit connected to the biologic signal and the controlled side of the circuit powered by a substantial power supply. Small variations in voltage on the controlling side affect the conductance through the transistor, thereby altering current flow through the controlled side. The output of a single-ended amplifier is a magnified representation of the input to the amplifier

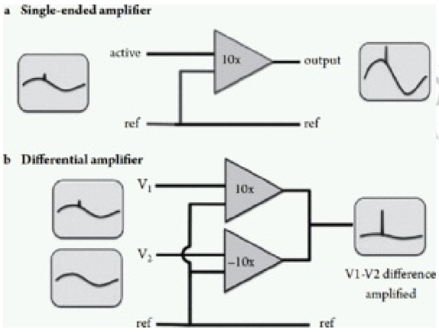

Figure 2-18:

a: Single-ended amplifier: where the input and output are in reference to a common level so the amplified output is similar to the input, just larger.

b: Differential amplifier: where there is amplification, inversion, then addition so that the output is the amplified difference between the two inputs.

Differential amplifiers are composed of two elementary single-ended amplifiers plus a subtracting circuit. Two input signals are used. Both are amplified by the single-ended amplifiers. Then, the amplified output from one is subtracted from the amplified output of the other. This difference is displayed and represents the differential output. The output of a differential amplifier is the amplified difference between the signal at two inputs.

Most amplifiers in routine electrophysiological equipment are differential amplifiers.

Signal Processing

Analog Devices

The first amplifier encountered by the biologic signal is the preamplifier. The preamplifier raises the amplitude of the signal so that it rises far above electrical noise. Many devices have the first phase of amplification in the head box.

The amplified signal is then large enough that there is likely less further electrical contamination of the signal. This signal is then passed through a series of filters. The high-frequency filter and low-frequency filter are in separate stages. The filtered signal is then fed into a powerful driver amplifier. The potentials required to move pens on a paper display are orders-of-magnitude greater than the potentials arising from the brain.

Digital Devices

Digital signal processing begins with preamplification of the raw signal, as described for analog signal processing. Then, the amplified signal is fed to an analog-to-digital converter (ADC). After the digital conversion, the montages are generated by calculations on the digital signal (see Figure **2-19**). Filters are also calculations on the digital data, and the type of calculations differs between devices. Once the signal is processed, the data is displayed on a monitor, just as any other graphical data. Power-spectral analysis or other mathematical handling can also be performed.

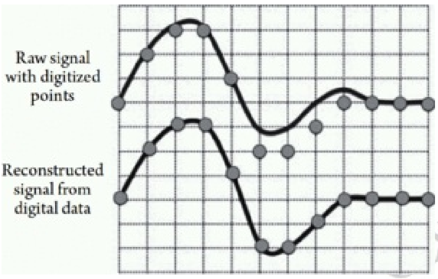

Figure 2-19:

An analog (continuously variable) signal is essentially placed on an X/Y grid where the X axis is time and samples are taken at specific times. The Y axis is voltage with specific voltage levels and the measurement is of the voltage level exceeded or met by the analog signal at each of the sample times. Then connecting the dots produces a digital representation of the analog signal.

Analog-to-digital converters (ADC) effectively plot the raw signal on a discrete time/voltage grid. They do this by sampling the voltage levels of the signal at specified intervals, so the time axis is not continuous but at discrete times. Similarly, the voltage levels that are discerned are discrete, with an interval that is defined by the gain used. Modern ADCs used in EEG machines have a maximum time resolution of about 4 μsec (250,000 samples/sec) and maximum voltage resolution of about 15 μV. Front-end analog amplification further improves the voltage resolution. The very fast conversion rate allows for a single ADC to convert multiple channels.

Filters

Overview

Filters alter the frequency composition of EEG so that we can more easily see the frequencies of interest. Raw EEG signal is composed of a broad range of frequencies, only some of which are relevant to routine interpretation. Frequencies slower than 0.5 Hz and faster than 70 Hz are of little value and can obscure the other frequencies.

Filter action

Frequency composition of the signal can be altered by the three basic filter types:

- High-frequency filter (HFF);

- Low-frequency filter (LFF);
- 60-Hertz (or notch) filter.

The HFF attenuates the higher frequencies, whereas the LFF attenuates the lower frequencies. The 60-Hz filter attenuates frequencies around 60-Hz. The mechanism of this, however, is complicated. There is not a precise cut-off, but rather a decay in amplitude of these frequencies near the selected set frequency. This decay is called the *roll-off*. The signal drops off by a certain amount per octave of frequency, Therefore, the filter effect is described by the filter type, the cut-off frequency, and the roll-off.

The 60-Hz filter is essentially an HFF and an LFF combined, with a maximal attenuation at 60-Hz. However, frequencies slightly faster and slower than 60-Hz are also attenuated to a lesser extent, and there may be some phase changes, though these changes are usually clinically insignificant.

Filters are often used to remove artifacts from EEG signals. Some artifacts have frequencies different from most EEG frequencies of interest.

Common artifacts are:

- Electrical artifact;
- Cardiac (EKG);
- Muscle (EMG);
- Tongue movement (glossokinetic);
- Eye movement;
- Sweat;
- Head movement;
- Respiratory movement.

The first three are high-frequency, and can be attenuated by HFF, but this may also attenuate important fast activity, such as spikes and sharp waves. Therefore, it is best if we can remove some of these electrical artifacts without filtering.

The slower artifacts can be attenuated by LFF, but this also can attenuate some of the slower physiological signals, such as frontal intermittent rhythmic delta activity (FIRDA) or polymorphic delta, and can actually change the morphology of some slow activity to appear as faster transients.

Physics of Filters

There are three basic types of filters:

- Passive filters;
- Active filters;
- Digital filters.

Passive filters are described in detail because they show the mechanism of filters. However, most filters in modern EEG equipment are active or digital. Passive filters are so called because they modify the signal without use of an exogenous power source. Active filters use transistors and a power supply to filter the signal. Digital filters are calculations performed on the digital data created from an analog signal.

The basic construction of the passive filter is the RC circuit (resistor-capacitor circuit; see Figure **2-20**). The RC circuit is a resistor and a capacitor in series with a power supply. Current flows through the conductor in the direction from the positive side of the power supply to the negative side. We are speaking of positive current, which is an electrical convention. In reality, current is electrons flowing from the negative end of the power supply to the positive end. The effect of the RC circuit can be best seen if meters are placed across the resistor and capacitor and a measurement of current is made.

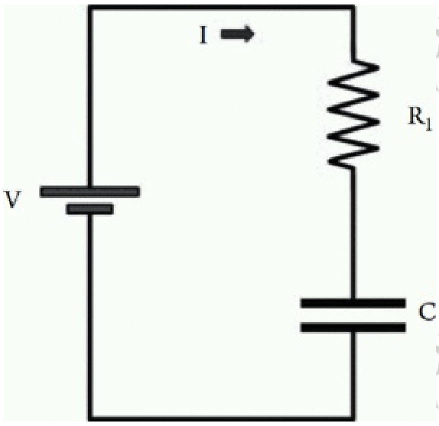

Figure 2-20:

Resistor-capacitor or RC circuit. Resistor (R) and capacitor (C) are in series with a power supply (V). Current (I) moved through the circuit.

Meters applied to the circuit will show a potential difference, which in the case of resistor is the voltage drop—a term which indicates that the applied voltage of the power supply is attenuated by passage through the resistor (see Figure **2-21**). For the capacitor, the measured voltage difference is the charge built up across the plates. Since electrons cannot jump from plate to plate in the capacitor, as current flows, electrons build up on one side of the capacitor and repel electrons on the opposite plate, making them flow off through their conductor. This is capacitive current.

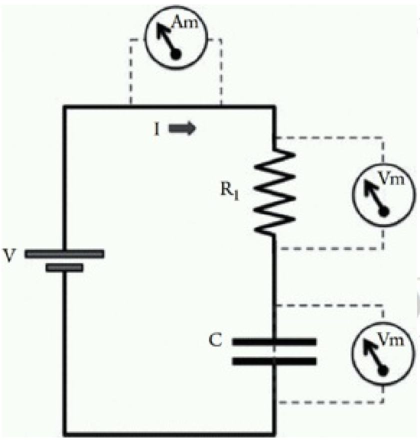

Figure 2-21:

RC circuit as in Figure **2-20**, but meters are placed to measure the voltage differences across the resistor and capacitor and to measure the current.

The actual recordings that would be obtained are shown in Figure **2-22**. For this illustration, a square-wave pulse is delivered by the power supply, equivalent to having a battery switched on for a second then switched off, yet leaving the connectors in place. A meter placed across the terminals of the power supply (V) shows the square-wave. The voltage causes current to move through the circuit (I). Current charges the capacitor (C). The voltage measured across the capacitor has a gradual increase because it takes time for the capacitor to charge. The voltage plateaus because the maximum voltage that can develop across the capacitor is governed by the voltage of the power supply. When the voltage pulse is turned off, the voltage across the capacitor gradually decays because it takes time for the electrons displaced on either side of the capacitor plates to return to their base state—equal electrons on both sides.

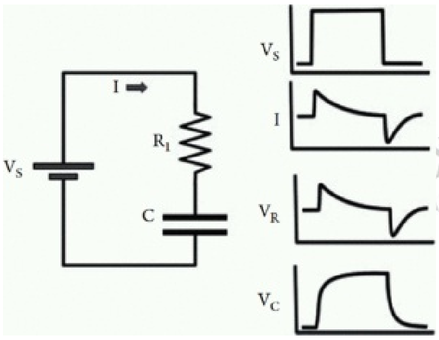

Figure 2-22:

A step change in voltage, positive 1 volt, is applied and the graphs show the changes in voltage difference and current with onset and offset of the step voltage. Current is initially large, but as the capacitor is charged, that voltage opposes the supply voltage, and as the capacitor becomes fully charged, current stops. When the applied voltage is zeroed, the capacitor discharges with current moving in the opposite direction. Voltage across the resistor varies directly with current, from Ohm's law.

The current flowing through the device (I) as measured by the ammeter has a complex waveform because of the capacitor. When the voltage is first turned on, there is a lot of current flowing through the circuit, giving the high spike of current. With current flow, there is buildup of charge across the capacitor, and this potential difference opposes the further flow of current, since it is in the opposite direction to the applied voltage. Therefore, the current is dependent on the difference in voltage of the power supply and capacitor, giving the gradual decline. When the voltage across the plates of the capacitor is equal and opposite to the voltage of the power supply, current ceases.

When the power supply voltage is switched off, the charged capacitor is now the only source of electromotive force (EMF) in the circuit, so current flows in the reverse direction to the initial current, hence the negative current spike.

The voltage measured across the resistor looks exactly like the current measurements because the voltage drop across a resistor is equal to current multiplied by resistance:

Ohm's law: $V = I \times R$

Since resistance is a constant, the voltage drop across the resistor is directly proportional to the current, so the relationship is linear.

What does this have to do with filters? The RC circuit is the simplest filter. Looking at the single step voltage just presented, the voltage measured across the capacitor looks like the signal voltage but with the high-frequency component filtered out—you can see what the signal voltage was, but not how fast it got there. In contrast, the voltage measured across the resistor looks like a differential (dV/dt) of the signal voltage (V). We can see the positive change in potential as the pulse starts and the negative change as the pulse stops, but we cannot see the plateau in voltage; essentially, the low frequency component has been filtered out.

Rule: For the RC circuit, the voltage across the capacitor looks like a high-frequency filter signal and the voltage across the resistor looks like a low-frequency filter signal.

This is a demonstration of passive filters, and the simplest version—the RC circuit. Active and digital filters work in a similar fashion, but their physical function is greatly different.

Filters in Practice

Passive filters, such as the RC circuit as just one example, have greater importance in generation of noise and distortion of signal than in equipment design. The electrode leads have inherent resistance and the proximity of the leads and other wires provides capacitance. Therefore, unintentional RC circuits can distort the signal voltage arising from the brain in unpredictable and changing ways.

Active filters are circuits involving semiconductors that amplify and attenuate the signal in a frequency-dependent fashion. Though the exact function is not presented here, suffice it to say that frequency-dependent amplification involves feedback circuits that attenuate certain frequencies, and the active filters are not constrained by the high- versus low-frequency filtering function—specific frequency bands can be accentuated or attenuated.

Digital filters are calculations performed on the digitized data. The calculations can be of many types, including smoothing across multiple data points, often with weighting, and attenuation of specific frequencies. Digital filtering is performed on the digitized data after analog amplification and analog-to-digital conversion.

Signal distortion occurs when the filtering process alters the appearance of signals within the frequency band of interest. For example, if the low-frequency filter setting is high, then delta activity will not only be reduced in amplitude, but differentiated, making a faster component that was not in the original signal. Similarly, if a high-frequency filter is set too low, spike activity will be blunted, perhaps giving the appearance of a normal physiological potential of lower frequency, again not part of the original biological signal. A 60-Hz filter can also attenuate spikes, though with modern equipment, this is not as problematic as it once was.

Phase shift occurs when a rhythm is passed through a filter. The most common manifestation of this is a phase lead; this is when the rhythm appears to move ahead in time, due to a differentiating effect of the filter system. Consider a sine wave as shown in Figure **2-23**.

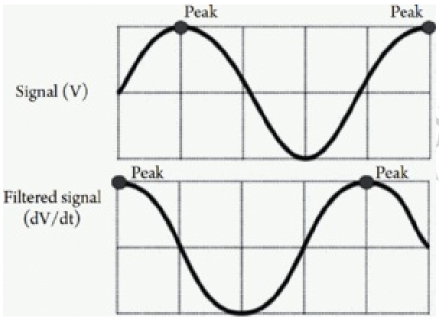

Figure 2-23:

Filters not only alter the frequency response of the signal but can also produce a phase shift, where the peaks of the waves are not simultaneous with those of the input signal. In this example, a filter has caused a phase-lead, where the filtered signal is ¼ cycle or 90 degrees ahead of the native signal.

The original signal wave is shown on top, with peak positivity 1/4 cycle from the beginning (i.e., 90 degrees). The wave is differentiated to filter out the low frequencies. This is like the low-frequency filter. Every point of the lower wave is dV/dt, or the change in voltage over time; dV/dt is most positive during the rising phase of the native wave, most negative during the falling phase of the native wave, and zero at the flat points—peak positivity and negativity of the native wave. When the points of peak positivity are highlighted by dots to show a marker of the cycle of the wave, you can see that the filtered wave is 1/4 cycle or 90 degrees ahead of the native wave.

Phase shift is not important for most EEG applications. However, spikes may appear earlier because of this phase-shifting effect, though this small effect is not clinically important. Note that phase shift can occur with digital filters as well as with analog filters.

Filter Settings

Filters are set to default values when the EEG machine is started. The most commonly used default values are:

- Low-frequency filter = 1 Hz;
- High-frequency filter = 70 Hz;
- 60-Hz filter = off.

The LFF may be decreased to better see some slow activity, though most physiologic and pathologic slow activity is seen well with default settings. The LFF is increased if there is slow activity that at least partially obscures the recording, including specifically sweat artifact. Unfortunately, increasing the LFF may also attenuate and thereby obscure some slow activity of clinical interest such as focal or generalized slowing.

The HFF is almost never increased. Reduction of the HFF is usually done to attenuate fast activity, which can obscure the recording. This can include electrical artifact and muscle activity (EMG). The former is best dealt with by the 60-Hz filter as well as improving the recording situation. Unfortunately, lowering the HFF may attenuate and blunt some physiologic fast activity such as epileptiform discharges. This means that the epileptiform activity falls into the noise of the recording.

The 60-Hz filter is most commonly needed when performing EEGs in the ICU or other portable position. In the office laboratory, this filter is rarely needed. In the hospital laboratory, the filter should not be needed, but this is not always realistic.

Electrodes

Overview

Electrodes are often given an afterthought in the performance of EEG, however, electrode properties are a critical part of the EEG system, and even minor deviations in the quality or placement of electrodes can greatly alter the recording. At times, electrodes are considered to be mere junctures, connections in the circuit comprising the brain and EEG equipment. However, the electrode and it’s interface with the scalp does have the ability to store and modify electrical signal.

Electrode Basics

Electrodes are connected to the scalp with a conducting gel, which serves a malleable extension of the electrode. Without this extension, any minor movement of the head would result in mechanical disturbance of the electrode-scalp interface, producing electrical artifact.

For most purposes, electrode basics are critical to day-to-day performance of EEG.

Some important technical requirements of electrodes and electrode placement are as follows:

- Electrodes of the same type and manufacturer;
- Equal lead length;

- Equal electrode impedances;
- Leads are not in proximity to other devices;
- Leads are not coiled.

Electrodes should all be of good condition and be of the same type and from the same manufacturer.

Electrode Theory

The electrode-amplifier interface is crucial to the understanding of electrode theory. A circuit diagram can be drawn that encompasses some of the essentials of the patient-electrode-amplifier interface.

Referring to Figure **2-24**, the signal voltage (Vs) is generated by the brain and conducted to the scalp. The electrode resistance (Re) is really impedance, which indicates frequency-dependent resistance. The current flows from these electrodes through the leads and to the input of the amplifier. The input of the amplifier is high-resistance, which results in little charge being required in order to detect a voltage. Therefore, the input resistance (Rin) should be much larger than Re and the resistance of the body from which the recording is made. Again, while we are speaking of resistance, impedance is a more accurate term.

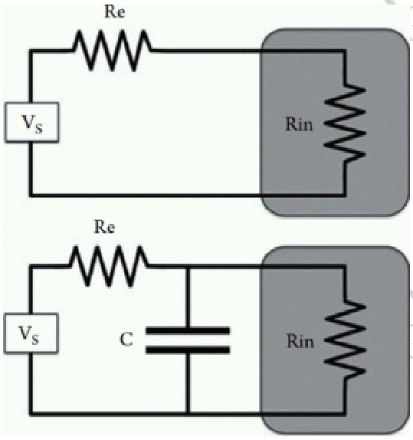

Figure 2-24:

Top: Diagram of the electrode-amplifier interface. VS is the signal voltage from the body. Re is the electrode resistance. Rin is the input resistance of the amplifier. The signal voltage is equal to the sum of voltages across the electrode (Re) and the input resistance of the amplifier (Rin).

Bottom: Same diagram as in A, but a small capacitance (C) is inserted into the circuit. This capacitance is created by proximity of the electrode leads and electrodes.

In the second diagram, there is a small capacitor between the electrode leads. This is not a structural capacitor but rather is due to proximity of the leads. This capacitance, along with the resistance of the electrode-patient interface, creates an RC circuit that can modify the recorded signal. The effect of this capacitance is to distort the incoming signal, essentially acting as a filter.

The signal seen by the amplifier is the most faithful representation of the input from the brain when all of the technical requirements for electrodes noted above are met and when the effects of noise-causing errors have been minimized.

Electrode Composition

Electrodes are composed of a variety of metals. While silver and gold have been traditionally used, a variety of other metals are used. Electrodes are reversible or irreversible. Reversible electrodes include the typical silver chloride electrodes. Reversible electrodes have easy bidirectional chemical reactions accounting for the movement of charge. Non-reversible electrodes have difficulty with electron flow in one direction, essentially conducting electric charge mainly in one direction well, and the opposite direction less well. A junction potential can be developed across interfaces, which can create electrode pops and distort the frequency response of the recording system.

Needle Electrodes

Needle electrodes are seldom used for EEG, being used mainly for EMG. Fixation of scalp electrodes is so good that needle electrodes for EEG are all but obsolete.

Intracerebral Electrodes

Subdural strips and depth electrodes are commonly used for presurgical monitoring of patients with epilepsy. Subdural strips are metallic electrodes that are similar to those used for scalp recordings. The direct continuity of the electrode metal with the brain tissue is less important than the field of recording. The exposed area of metal is less than with scalp electrodes, so that the field of recording is more restricted.

Depth electrodes are inserted within the brain tissue to a specified target. The exposed area on depth electrodes is extremely small, again restricting the recording field of view.

Analog-to-Digital Conversion and Digital Data Manipulation

The analog signal recorded from the brain is amplified to increase the size of the signal so that there is sufficient signal to obscure noise introduced from the conduction from head box to the analog-to-digital converter. Subsequently, the analog signal is converted to digital format using an analog-to-digital converter (ADC). The ADC performs analysis on the analog signal, sampling the signal at specified times and making measurements. Analog-to-digital conversion was discussed above, with Figure **2-19** illustrating the concept.

The frequency of sampling is dependent on the hardware, but generally, most electrophysiological equipment samples fast enough to have a good representation of time-dependent changes in the biological signal. The sample is taken in a microsecond, then the converter waits until it is time to sample again. Most ADC devices use the same converting circuitry to sample more than one channel, so a sample is taken from channel 0, then channel 1, then channel 2, and so on. When the ADC has converted the complete list, it waits until the next time. The interval between samples is the intersample interval, or ISI. This is sometimes called the *dwell time*, although this is a misleading term and should be discarded. The number of samples per second is the sampling rate, not the sampling frequency, the latter being wrong because this is a description of

amount per unit time and not frequency.

In practice, the time resolution (sampling rate) and voltage resolution (amplitude of voltage threshold levels) is so good that the reconstructed waveform would be virtually indistinguishable from the native waveform, and not a rough approximation as in Figure **2-19**.

The digital data is able to be manipulated in a way that is impossible with analog data. Filters have already been discussed, and most of this discussion centered on analog filters. Digital filters are calculations performed on the digital data.

The calculations can accomplish various tasks, including:

- Remove high frequencies;
- Remove low frequencies;
- Remove specific frequencies, such as 60-Hz line power artifact;
- Identify amount of specific frequency bands (power spectral analysis);
- Identify potentials that might be epileptiform activity (spike detection);
- Identifying sleep stages (particularly for sleep studies, not discussed here).

These calculations are not perfect. Frequency and timing distortion can occur, including phase shifts.

Digital Displays

Computer displays are most commonly used. Paper records are considered obsolete and as such are not discussed in detail. Modern machines display the EEG data on a computer screen.

The mechanisms to show data on the screen are part of computer operating systems, and the programming consists of calculations then telling the computer what you want the picture on the screen to look like. Few modern programs are written from scratch, using assembly language. More commonly, they are written in high-level languages that rely on small sub-applications (applets) or runtime-routines for performance of the elementary processes of input and drawing, for example.

The displays required for the interpretation of EEG are generally higher resolution than most budget displays. The reader is encouraged to spend the extra money for larger and higher resolution displays. This greatly improves the ease and accuracy of interpretation.

Standards

Overview

Standards for performance of EEG are established by routine clinical practice and by published recommendations. Many of the technical aspects have already been discussed. Chapter 3 presents filter settings, amplifier gain, display settings, performance of activation methods, documentation, and storage.

Routine EEG

There are routine minimum standards that which should be met and are outlined in Table 2-3. Special comment about some of the elements is deserved.

Table 2-3 Technical Requirements for Routine EEG

Standard	***Description***
Routine EEG should met the following minimum standards	At lest 20 min of relatively artifact-free recording, 30 min for brain death studies.
	Performance of activation methods when appropriate.
	Use of standard filter and gain settings, modified as needed, depending on the clinical situation and the appearance of the recorded EEG
	Recordings must be performed by a qualified technician.
	Recordings must be interpreted by a qualified physician.
Standard recording parameters	HFF = 70 Hz
	LFF = 1 Hz
	Sensitivity at start = 7 μV/mm
	Electrode impedance = 100–5,000 ohms
	Standard recording montages

Duration of recording: While 20 minutes is the minimum for most patients, diagnostic sensitivity is served by longer recordings, even of 30–60 minutes. Also, if a patient appears to be approaching some event, then continued recording is certainly needed. Technicians need to be sensitive to the clinical situation.

Activation methods: Photic stimulation is performed on most patients. Hyperventilation (HV) has a number of contraindications discussed elsewhere, but separate from that, HV is not performed on intubated patients.

Filter and gain: Standard settings are used initially, but these may have to be adjusted to achieve a quality recording. In general, this is discouraged since adjusting these may alter the recording so that an incorrect clinical interpretation is rendered.

Electrode impedance: A wide range of electrode impedances is proposed, but in general the impedances should be as similar as possible. Similar impedances are more

important than low impedances. Similarly, it is not always possible to maintain impedances less than 5 kohm, so in that circumstance at least we should have the impedances approximately equal.

Qualified technologist and physician: What serves as qualified for technician and physician can be debated, but comprehensive training and practical experience are essential. The training and experience of the practitioner are more important than the paper board certification. One could pass neurophysiology boards by reading texts, but this would not suffice as adequate interactive training.

Standard montages are discussed in this text. Most digital machines allow for changing the montage during review.

Recording storage: The recordings are to be kept, but most states do not give specific guidelines for maintenance of the records. Each lab should consult regulations in effect at their locations. But in the absence of defined regulations, the following would be reasonable:

- Keep reports indefinitely;
- Keep digital recordings of adults for at least 10 years;
- Keep digital recordings of children until they reach 21 years of age.

Generators of EEG Potentials

EEG activity is due to charge movement in neuronal membranes. It is attractive to think of EEG activity as originating in defined nuclei, but in general, the electrical potentials represent the summed electrical activity from a substantial number of neurons.

EEG recorded from the scalp is generated by the cerebral cortex, with the portion of the cortex adjacent to the skull being the greatest contributor.

Cortical Potentials

Most cortical efferents are oriented perpendicular to the cortical surface. The gyration of the cortex results in only a fraction of the cortical efferents being oriented perpendicular to the scalp. Therefore, those neurons would be expected to have a disparate contribution to the surface-recorded EEG. Electrical activity at the large cortical neurons produces dipoles that are summed to generate the scalp EEG. It is thought that summated excitatory postsynaptic potentials (EPSPs) and inhibitory postsynaptic potentials (IPSPs) are responsible for most of the EEG activity recorded at the scalp. Surprisingly, action potentials probably have a lesser contribution to the EEG. The longer duration of postsynaptic potentials is more in line with the duration of most scalp recorded EEG activity, while action potentials are too short.

Scalp Potentials

Scalp electrodes are unable to see all of the electrical activity of the brain. Synchronous activity of numerous neurons is required for there to be a recordable wave from the scalp leads. One estimate is that approximately 6 cm^2 of cortical surface must be synchronously activated in order for there to be a potential recorded at the surface. Scalp potentials are volume conducted through the skull and scalp, which results in considerable attenuation of the activity. There is greater attenuation of potentials that rise and fall rapidly (i.e., higher frequency potentials).

Generation of Abnormal EEG Activity

Abnormal EEG activity can be epileptiform or non-epileptiform (see Table 2-4). The two most important types of abnormal EEG activity are slowing and epileptiform activity. Slowing indicates disordered function of the neurons, whereas epileptiform activity indicates abnormal synchronous activity.

Table 2-4 Abnormal EEG Activity

Category	Differentiation	Description
Epileptiform	Single vs. repetitive	Single discharge is typically interictal, and there are usually multiple single discharges during an EEG recording
		Repetitive discharges are usually at least 1/sec, usually faster, and are commonly associated with clinical seizure activity
	Focal vs. multifocal vs. generalized	Focal epileptiform activity can be due to a local structural lesion or associated with local circuit abnormality not due to an identifiable structural lesion
		Multifocal epileptiform activity usually indicates a developmental or multifocal process, sometimes metabolic.
		Generalized epileptiform activity which is primary, i.e., not spread from a focal onset, usually indicates a genetic or developmental process.
Non-epileptiform	Attenuation or suppression	Attenuation is reduction in amplitude. With normal frequency composition can be due to intracranial or extracranial fluid collection. With loss of faster frequencies suggests focal structural lesion, i.e., infarction.
		Suppression is marked loss in amplitude and indicates severe abnormality in cortical function from almost any cause. Focal suggests localized damage, generalized is often seen with hypoxia and other diffuse causes.
	Slowing	Focal slowing is usually due to a localized structural lesion.
		Generalized bisynchronous slow activity is usually metabolic or due to deep lesions.
		Generalized asynchronous slow activity has the broadest differential diagnosis but is usually a diffuse, multifocal, or metabolic/toxic process.
	Abnormal frequency composition	Abnormal frequencies other than slowing include excessive fast activity especially in an unexpected distribution, e.g. Alpha from the frontal lobes in a patient with hypoxic encephalopathy is abnormal; Alpha from the occipital region of an awake patient is normal.
	Abnormal transients	A wide range of transients develop that are not strictly speaking epileptiform but are abnormal. Frontal intermittent rhythmic delta activity and triphasic waves are examples of abnormal transient potentials.

Attenuation and Suppression

Attenuation and suppression are sometimes used interchangeably, but they are slightly different. Attenuation refers to reduction in the amplitude of the EEG; this says nothing about the frequency composition. Suppression is also lower amplitude but is typically very low in amplitude and often is associated with a loss of faster frequencies.

Focal Attenuation

Focal attenuation usually indicates a cortical lesion or reversible cortical dysfunction, since EEG activity is generated at the cortex. Focal attenuation could also result from an increase in tissue between the cortex and the recording electrode.

Since each EEG channel displays the potential difference between electrodes, attenuation will be seen if there is reduction in the potential difference between electrodes in a channel. In bipolar recordings where each channel displays the difference between adjacent electrodes, attenuation will be seen if there is an electrical shunt eliminating the potential difference. Such a shunt can be due to smeared conductive electrode gel connecting the two electrodes, or a chronic subdural hematoma.

Generalized Attenuation

Generalized attenuation may suggest a generalized cortical injury or transient dysfunction. However, an attenuated EEG in adults could be a normal variant, as long as the frequency composition is normal; a tense individual may have a low-voltage fast background, not showing the normal appearance of relaxed wakefulness.

Slow Activity

Focal Slow Activity

Focal irregular slow activity is usually due to a localized subcortical structural lesion (or dysfunction). Focal slow activity seems to be a result of deafferentation of the cortex from subcortical structures.

Generalized Bisynchronous Slow Activity

Generalized bisynchronous slow activity can be intermittent or continuous. It may be due to disordered circuit loops between the cortex and thalamus. This type of abnormality is reported in conditions affecting both cortical and subcortical structures, as well as in a number of toxic/metabolic encephalopathies, and in deep midline lesions. In the latter situation, generalized bisynchronous slow activity may be referred to as a projected rhythm.

Generalized Asynchronous Slow Activity

Generalized asynchronous slow activity has a broad differential diagnosis, though it usually indicates encephalopathy. Some of the possibilities include degenerative processes, encephalitis, extensive multifocal vascular disease, and toxic and metabolic disorders. This pattern is likely due to poor synchrony and rhythmicity of regions of the cortex.

Epileptiform Activity

Epileptiform activity involves abnormal synchronous activation of many neurons. Corresponding to focal epileptiform activity at the cellular level is a wave of depolarization called the paroxysmal depolarization shift (PDS).

Paroxysmal Depolarization Shift

The PDS is the fundamental electrophysiological substrate of focal epileptiform activity. The PDS cannot be recorded with scalp electrodes but requires cortical microelectrodes for detection.

The PDS is an extracellular field potential where there is a wave of depolarization followed by a wave of repolarization. High-amplitude afferent input to the cortex produces depolarization of cortical neurons sufficient to trigger repetitive action potentials, which in turn contribute to the potentials recorded at the surface. Repolarization due to inactivation of interneurons is followed by a brief period of hyperpolarization.

Cyclic depolarization and repolarization are believed to be the cortical counterpart to rhythmic spike-and-wave discharges seen sometimes in epilepsy. The rhythmicity may be at least in part due to the inability of cortical neurons to sustain prolonged high frequency discharges, but in addition is likely due to built-in circuitry to inhibit repetitive discharges. The repetitive discharge is not terminated by neuronal exhaustion but rather by this mechanism of inactivation. There may be membrane effects independent of active inhibition to terminate seizures, yet the exact mechanisms of seizure termination are still under study.

Spikes and Sharp Waves

Sustained depolarization of a neuron can result in multiple action potentials on the crest of the depolarization. If one neuron is activated by this burst, there will likely be no neurologic symptoms and the discharge will not be recorded from scalp electrodes. However, if there is synchronous activation of multiple neurons, this can be recorded on scalp electrodes as a surface negative spike or sharp wave.

Spikes and sharp waves are occasionally surface positive. In neonates, positive spikes and sharp waves may have a particular significance due to association with intraventricular hemorrhage.

Seizures

There is a grey zone between interictal activity and ictal activity. Repetitive discharge on the crest of the PDS may be prolonged to produce a seizure. In addition, a prolonged discharge of one neuron may then entrain a group of adjacent neurons to depolarize and repetitively discharge, thereby producing expansion of the region of epileptogenic activity and prolongation of the discharge to duration which is clearly ictal.

Oxford Medicine

Atlas of EEG, Seizure Semiology, and Management

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EEG Technology

Chapter: EEG Technology
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Overview

EEG technology used in clinical and video EEG recording are similar; in fact, most modern equipment can serve both purposes, routine office EEG recordings and long-term video EEG recordings. This was not true years ago. When acquiring equipment, we suggest that you make the modest extra investment to have video capability. This is invaluable for evaluation of patients with spells of uncertain etiology, and establishing the diagnosis is much easier with direct correlation of behavioral with electrocerebral activity.

EEG Methodology

Electrode Placement

The standard 10-20 electrode placement system is used by virtually all laboratories. Additional electrodes are also sometimes used including:

- Sphenoidal;
- Nasopharyngeal;
- Supraorbital;
- Nasoethmoidal;
- Eye-movement;
- Electromyogram (EMG);
- Electrocardiogram (EKG).

In addition to extracranial electrodes, intracranial electrodes are used for presurgical evaluation and can be of several types, with subdural strips and depth electrodes being the most commonly used.

Measuring the Head and Electrode Positions

“10-20” Electrode Placement System

The 10-20 electrode placement system is a standard for placement of scalp electrodes used by virtually all neurophysiology laboratories. The 10-20 system uses a systematic measurement process to create reproducible electrode positions. Figure **3-1** shows a diagram of the electrode positions, and a variation of this diagram appears as an option on some EEG software packages. Many readers prefer to have the head diagram on the screen, even though the individual channels are labeled.

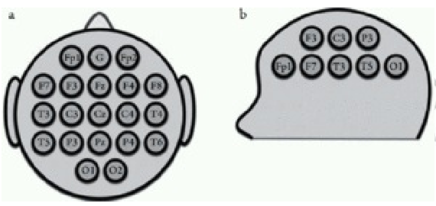

Figure 3-1:

The “10-20” electrode placement system is routinely used. The system is based on established measurements, as described in the text. a: View from the top. b: View from the left side.

Terminology for most electrodes is two characters. The first character is the region and the second character is an element in that region. The regions are:

- Frontal (F);
- Central (C);
- Temporal (T);
- Parietal (P);
- Occipital (O);
- Auricular (A);
- Frontopolar (Fp).

In addition, there are electrode designations for nasopharyngeal, sphenoidal, depth, submental EMG, eye movement, EKG, and other physiological recordings.

The second character of most electrode position designations follows these rules:

- Odd numbers are left-sided;
- Even numbers are right-sided;
- Lower-case "z" is midline;
- Lower numbers are more anterior and/or medial to higher numbers;
- Not all numbered positions are used for routine EEG.

Therefore, the left central electrode is C3, and the corresponding position on the right is C4. Cz is in the midline. C1 and C2 are not used in routine recording. F7 is lateral to F3, and T4 is anterior to T6.

The importance of accurate electrode placement cannot be overemphasized. Sloppy electrode placement, based on estimates and "feel" result in inaccurate cortical localization.

Notice that F7 and F8 have several names, reflecting that they can record both anterior temporal or inferior frontal activity (see Figure **3-2**). Examining the field of discharges can be essential to determining the source of recorded activity (see Figure **3-3**). For example, if the field is F8 and T4, then F8 activity is anterior temporal, while if the field is F4 and F8, then F8 is likely recording inferior frontal activity. If F8 alone is involved, or if the field involves F8 and Fp2 (Fp2 records frontopolar activity but could also detect dipoles originating at the temporal tip), then it is not clear if F8 is anterior temporal or inferior frontal, hence the name *anterior sylvian* (our preferred term) or *frontotemporal*. This uncertain status of F7/F8 has resulted in the exploration of "true" anterior temporal electrodes (discussed below).

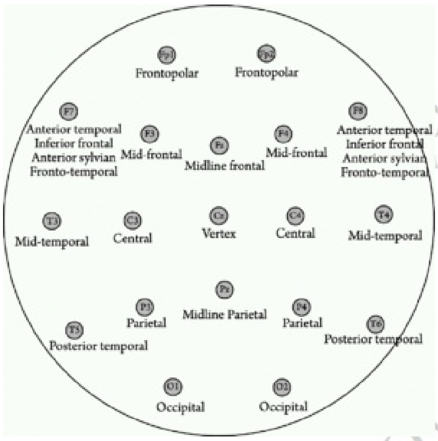

Figure 3-2:

These are additional electrodes occasionally used.

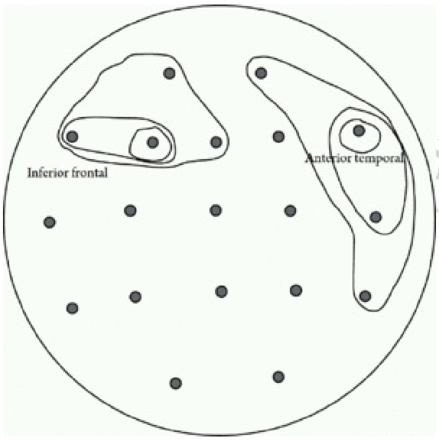

Figure 3-3:

The left field suggests activity in an inferior frontal location, whereas on the right is an anterior temporal location.

On the left the field suggests that F8 is an inferior frontal electrodes, whereas on the right the field suggests that it is an anterior temporal electrode.

Other leads of interest include:

- Ear (auricular) with left being A1 and right being A2;
- Ground (G) electrode.

Measurement of the head:

- Measure the distance from the nasion to inion across the vertex. Mark a line at 50% of this distance at the top of the head.
- Measure the distance between the preauricular points, just in front of the ear. Mark a line at 50% of this distance at the top of the head. The intersection of this line with that of step 1 is Cz.
- Lay the measuring tape from nasion to inion through Cz. Mark 10% of this distance above the nasion for Fpz and above the inion for Oz. Fz is 20% of this distance above Fpz. Pz is 20% of this distance above Oz.
- Lay the tape between the preauricular points through Cz. T3 is 10% of this distance above the left preauricular point, and T4 is 10% of this distance above the right preauricular point. C3 is 20% of this distance above T3, and C4 is 20% of this distance above T4.
- Lay the tape from Fpz to Oz through T3. FP1 is 10% of this distance from Fpz, F7 is 20% of this distance posterior to Fp1. O1 is 10% of this distance anterior to Oz, and T5 is 20% of this distance anterior to O1. Measure in the same manner for Fp2, F8, O2, and T6 over the right hemisphere.
- Lay the tape from Fp1 to O1 through C3. F3 is half the distance between Fp1 and C3. P3 is half the distance between C3 and O1. Repeat for the right side, with the tape from Fp2 to O2 through C4. F4 is half the distance between Fp2 and C4, and P4 is half the distance between C4 and O2.
- Lay the tape from F7 to F8 through Fz, F3, and F4 to ensure that the distance between the electrodes is equal. Then lay the tape from T5 to T6 through Pz, P3, and P4 to ensure equal interelectrode distances.

Additional Electrodes Outside the 10-20 System

Additional leads are occasionally placed, although not as part of routine EEG performance (see Figure **3-4**). These include:

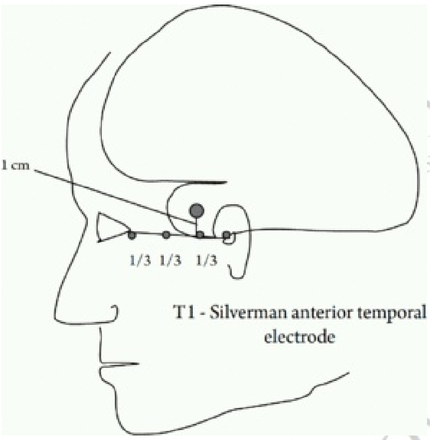

Figure 3-4:

Diagram of electrode placement for the T1 electrode.

- Silverman “true” anterior temporal (T1 and T2) electrodes to monitor anterior temporal activity;
- Zygomatic electrodes and cheek electrodes for monitoring of lateral-basal temporal lobe activity; and
- Supraorbital electrodes for monitoring anterior orbitofrontal activity.

The reason for the T1/T2 electrodes is that F7/F8, which are the anterior temporal electrodes, are physically located over the lateral inferior-posterior frontal region. They do record anterior temporal lobe activity, but may also record frontal activity. To monitor mesial-basal temporal activity, the most commonly used electrodes are sphenoidal electrodes. Nasopharyngeal electrodes were frequently used in the past, but are rarely used now because they are unstable, easily dislodged, and become more uncomfortable over time. Deep sphenoidal electrodes are inserted just below the zygomatic arch, 2 cm anterior to the line between the tragus and the condyle of the mandible. The needle is directed horizontally and approximately 10 degrees posteriorly. The tip should rest close to the foramen ovale (at a depth of 4–5 cm). Although their insertion is painful, sphenoidal electrodes are well tolerated and stable, making them ideal for recording seizures with long-term monitoring. Mini-sphenoidal electrodes are inserted in the same location to a depth of only 1 cm. This makes them possible to insert by EEG technologists. Although they are not as good as sphenoidal electrodes for detecting mesial-basal activity, their ease of insertion makes them useful for short-term recordings. Note that any inserted electrodes should only be placed by physicians well trained in their placement.

T1 electrode placement: The distance from the auditory canal to the outer canthus of the eye is measured and divided in thirds. T1 will be one cm superior to the mark closest to the ear canal.

“10-10” Electrode Placement System

The 10-10 electrode placement system is based on the same landmarks as the 10-20 system, but involves the addition of electrodes between 10-20 electrode positions (see Figure **3-5**). Although there have been several nomenclatures for this system, the one recommended by the American EEG Society (now the American Clinical Neurophysiology Society), is the modified combinatorial nomenclature. In this nomenclature system, the letters identify the location, particularly the coronal plane location, and the number (or z) refers to the position relative to the midline. The odd numbers (1 to 9) belong on the left, the even numbers (2 to 10) belong on the right, and z still stands for the midline. The smaller numbers refer to positions close to the midline and the larger numbers to positions farther away from the midline. In this new nomenclature, the 10-20

electrode names could be preserved, with the exception of T3/T4 and T5/T6. These electrodes lie in the same sagittal planes as F7 and F8 and needed to have the same numbers. T3 and T4 were therefore changed to T7 and T8. T5 and T6, the posterior temporal electrodes, are close to the temporo-parieto-occipital junction, and as they are in the same coronal plane as P3 and P4, were named P7 and P8. In this *Atlas*, both new and old names for these electrodes are used.

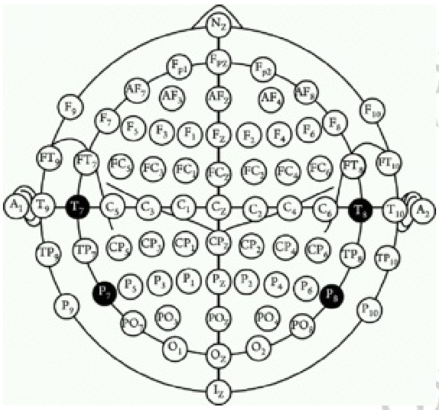

Figure 3-5:

The bold black electrodes are ones whose name was changed from the 10-20 system nomenclature.

The additional coronal electrodes planes created in the 10-10 system are AF for anterior frontal, FC and FT for frontocentral and frontotemporal plane, CP and TP for centroparietal and temporoparietal plane, and PO for parieto-occipital plane. Additional electrodes in the 10-10 system are rarely used in routine EEG recording. Even in epilepsy monitoring, it would be very impractical to use all the 10-10 electrodes. However, when the field of certain activity has to be clarified, selected additional electrodes can be used in a region of interest. For example, in suspected mesial frontocentral foci, FC1, FCz, FC2, C1, C2, CP1, CPz, and CP2 could be added for best delineation of the field. In left temporal lobe epilepsy, FT7, FT9, and T9 could be added and may obviate the need for T1 and T2 electrodes.

The following are the new and old names for the revised 10-20 system:

- T7 = T3;
- T8 = T4;
- P7 = T5;
- P8 = T6.

Applying Electrodes

Which to Use: Gel or Collodion

Electrodes are placed by either paste or collodion. Paste is commonly used for routine short-duration EEG recordings. Collodion is also sometimes used for routine recording, but is more commonly used for long-term recordings such as inpatient and ambulatory monitoring and sleep studies. Collodion takes longer to apply and remove, so that paste is preferentially used for routine recording. Before application of electrodes by either method, the skin must be prepared.

Application of Electrodes Using Gel

- Locate the positions for electrodes using the 10-20 electrode placement system.
- Separate strands of hair over the electrode positions using the wooden end of a cotton-tipped applicator.
- Clean dead skin and dirt from the region, using the cotton-tipped applicator and a skin-prep gel.
- Scoop some conductive gel into the electrode.
- Place the electrode in position over the skin.
- Put a 2"x2" gauze pad over the electrode and push it firmly onto the head, providing a seal, which prevents the electrode from falling off the scalp.

The electrodes are attached to the scalp using gel, which is a malleable extension of the electrode. The gel serves to maximize skin contact and allow for fixation on the skin, which minimizes the effect of small amounts of movement. The gel lowers the impedance of the electrode-skin interface.

Removal of gel-fixed electrodes is easy. The gauze pads are pulled off, then the electrodes are gently pulled off, tilting them to release the vacuum effect. Then, the gel left on the scalp can be largely removed by rubbing with a warm, wet washcloth. After the patient washes the hair that evening, all traces of the recording are gone.

Application of Electrodes with Collodion

- Prepare the head at the electrode positions as mentioned for electrode gel.
- Place the electrode on the scalp.
- Place a piece of gauze soaked with collodion over the electrode.
- Use compressed air to dry the collodion.
- Insert a blunt-tipped needle into the cup and scrape the skin to lower electrode impedance.
- Inject electrolyte into the cup of the electrode using the blunt-tipped needle.

Collodion is used preferentially for patients in inpatient monitoring units and for ambulatory monitoring. This is much more secure than paste for studies which are longer-term or where the patient is moving.

Removal of collodion-fixed electrodes is more difficult. First, the collodion is softened by use of a solvent, traditionally acetone but more gentle alternatives are available. Then the areas are cleaned as above. The degree of washing required is greater both immediately by the technician and later by the patient.

Special Electrodes

Special electrodes are helpful in a minority of patients, especially for pre-surgical evaluation. Table 3-1 summarizes some of the important special electrodes, and the following text describes them in more detail.

Table 3-1 Special and Invasive Electrodes

Electrode class	***Electrode type***	***Description***
Non-invasive	Sphenoidal	Inserted adjacent to the zygoma to the skull base. Used especially when temporal location is suspected. Alternative is mini-sphenoidal electrodes.
	Nasopharyngeal	Inserted through the nose to record especially mesial-basal temporal discharges. Unstable and uncomfortable, so seldom used and not for long-term recordings.
	Supraorbital	Applied over the orbit especially for orbitofrontal discharges.
	Needle	An alternative to disc electrodes for almost any scalp location, but offer no advantage and seldom used.
	Nasoethmoidal	Applied by ENT physician for recording from the inferior frontal region. Seldom used.
Invasive	Foramen ovale	Percutaneously inserted into the region of the foramen ovale for recording from the medial and basal temporal lobe.
	Subdural and epidural strips or cylindrical electrodes	Placed through burr holes and under or over the dura on the region of the cortex targeted on the basis of imaging, scalp EEG, and/or clinical suspicion. Our lab uses exclusively subdural strips.
	Subdural grid	Implanted through craniotomy, of varying size up to 8x8 matrix. Placed over a region of interest to refine localization of the epileptogenic zone as well as mapping cortical functions with electrical stimulation.
	Epidural peg electrodes	Implanted through small burr hole so that the distal aspect of the peg is touching the dura. Multiple pegs can be placed to cover large regions. Muscle artifact is eliminated.
	Depth electrodes	Placed stereotactically through burr hole, targeted on the basis of imaging, EEG, or clinical suspicion.

Sphenoidal Electrodes

Sphenoidal electrodes are used to record activity from the temporal lobe, which would not show on scalp recordings. The electrodes are inserted percutaneously adjacent to the zygoma until they reach the base of the skull. Sphenoidal electrodes should only be used by physicians trained in their insertion and experienced in interpretation of the recorded potentials.

Nasopharyngeal Electrodes

To record from the mesial-basal temporal cortex, nasopharyngeal electrodes were used in the past, but are now much less frequently used. These electrodes can be irritating and increasingly so with the passage of time. In addition, they are unstable and are likely to be dislodged with casual movement, as well as by movement with a seizure. They are certainly not appropriate for long-term monitoring beyond a few hours.

Supraorbital Electrodes

For patients with suspected orbitofrontal seizure origin, supraorbital electrodes may enhance the recording of epileptiform activity and ictal onsets from the anterior orbitofrontal cortex. It should be noted, however, that supraorbital electrodes will frequently record anterior temporal discharges. Therefore, the interpretation of activity originating in the supraorbital electrodes will depend on the field of this activity.

Needle Electrodes

Needle electrodes offer no advantages over conventional surface electrodes and should not be used for routine studies unless recording cannot be accomplished any other way. The risk of infection to the patient and technician is unacceptably high.

Nasoethmoidal Electrodes

Nasoethmoidal electrodes are impractical as they require placement by an ear, nose, and throat (ENT) specialist. They are seldom used in routine practice.

Invasive Electrodes

Invasive electrodes are used almost exclusively for presurgical evaluation.

Foramen Ovale Electrodes

Electrodes are placed using an introducer into the region of the foramen ovale. These electrodes are used mainly for evaluation of patients with seizure foci in the medial basal temporal lobe. These electrodes are available commercially from several sources, but should only be used by physicians well trained in their insertion, use, and EEG interpretation.

Subdural Strip Electrodes

Subdural strip electrodes are used to evaluate patients for epilepsy surgery. The strips are placed during surgery through burr holes. The strips allow for a detailed map of the recorded electrical activity. The strips are typically in an array on a small sheet, so there is spatial coverage over the cortical surface.

Subdural strip electrodes should only be used by physicians trained and experienced in placement and interpretation, and only as part of a comprehensive epilepsy intervention program.

Depth Electrodes

Depth electrodes are used to localize seizure foci for surgery. A depth electrode consists of an array of electrodes on a single barrel that is inserted into the brain, usually in the temporal lobe. There are multiple electrode contacts on the side of the electrode array, so superficial and deep electrical activity can be recorded. The electrodes are placed stereotactically on the basis of imaging, scalp, or subdural EEG data, and/or clinical suspicion.

Only trained and experienced epileptologists should use depth electrodes, and these are used almost exclusively for preoperative evaluation.

Physiologic Monitoring

It is often important to monitor physiological parameters in conjunction with the EEG (see Table 3-2). Electrocardiogram (EKG) is the most important and needs to be monitored in all patients. One reason is that EKG artifact often appears on EEGs and could result in confusion regarding the origin of some sharp potentials. Additional electrodes for physiological monitoring need to be used predominantly in neonatal EEGs, in brain death recordings, and in select situations, particularly for intensive care unit (ICU) recordings. They include, but are not restricted to the following:

Table 3-2 Physiological Monitoring

Parameter	***Recording method***	***Clinical use***
EKG	Electrodes below the right clavicle and left 5th intercostal space on the mid-clavicular line.	EKG artifact commonly contaminates EEG recordings, and EKG monitoring is essential to differentiate this from cortical sharp waves and spikes.
Eye movements	Electrodes placed above and to the side of the eyes in an array to map eye movements.	Eye movements are seen on scalp EEG and can be misinterpreted as frontal EEG. Also used during some sleep studies.
EMG	Disc electrode is placed usually on chin and/or arm or leg.	Recording muscle activity, especially in neonates during sleep. Of limited value in adults.
Respiratory	Chest transducer or airflow transducer.	Especially for polysomnography.
	Oximeter	Especially for polysomnography.

- Eye movement electrodes;
- Infraorbital electrodes (these are placed immediately below each eye, for distinguishing vertical eye movements from frontal EEG activity);
- Electro-oculogram leads (both electrodes are lateral to the eyes, one above the right eye, and another electrode below the left eye). These leads record eye movements. They are used mainly for neonatal EEG and for sleep recordings.
- Submental EMG electrodes;
- Respiration monitor (to monitor respiratory effort);
- Air flow monitor.

EEG technologists should be encouraged to be proactive and creative, adding electrodes as needed. For example, if the patient has right arm jerks and EEG potentials that may possibly be linked to these, the tech could add an electrode over the right arm, which would help the electroencephalographer in identifying a consistent relationship between the two.

EKG Electrodes

EKG electrodes are almost always placed for routine EEG, but especially are useful during long-term EEG monitoring and sleep studies. EKG monitoring is particularly helpful for patients having routine EEG when there are sharp transients that might be EKG or slow transients that may be pulse artifact (see Figure **3-6**). Because of the common cardiac and vascular contamination of the recordings, routine EKG lead placement is certainly reasonable, as long as adequate channels remain available for EEG electrodes.

Figure 3-6:

EKG artifact is best seen with ear-reference montages.

EKG must be differentiated from electrocerebral discharge.

Eye Movement Electrodes

Eye movement artifact is common due to the polarization of the globe. The globe can be considered to be a dipole, with the corneal region positive compared to the posterior retinal region. The recorded electrical activity is due to potential difference of the retinal pigment epithelium.

The patient in the recording shown in Figure **3-7** had rapid eye blinks that appeared after eye opening. On the left side of the figure is a normal background with posterior

dominant rhythm (PDR). At the marker in the middle of the page is eye opening with the expected attenuation of the background. Two seconds later, there is onset of eye blink.

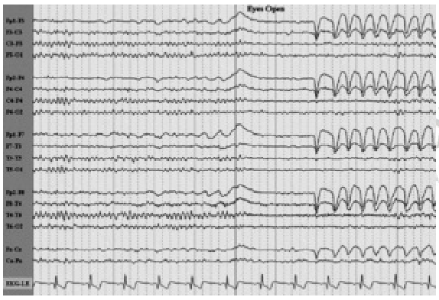

Figure 3-7:

Repetitive potentials on the right side of the figure from the frontal region are eye blinks.

Movement of the globe creates slow activity that is easily identifiable as ocular in origin when eye blink is vertical. However, lateral eye movements and roving gaze can easily be confused with pathologic frontal slow activity (see Figure **3-8**). Lateral and vertical conjugate eye movements produce disparate deflections on the eye leads, so that slow activity on the EEG can definitively be determined to be cerebral or ocular.

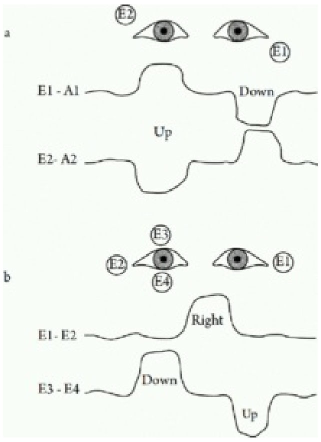

Figure 3-8:

Potential eye lead placements are shown.

a: Differentiates eye movement from frontal cerebral activity

b: Differentiates direction of eye movement

EMG Electrodes

EMG is a frequent contaminant of EEG recordings, especially in temporal leads. EMG artifact may be mistaken for sharp activity. A noncephalic EMG electrode can be used for identification of adult EMG activity but has limited use in most routine studies (see Figure **3-9**).

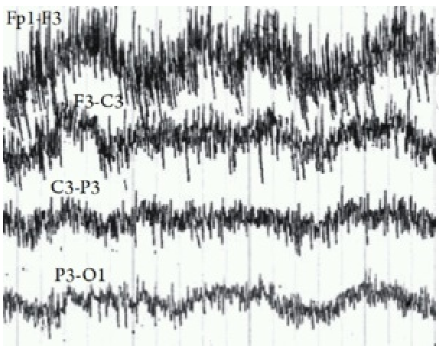

Figure 3-9:

This is the left parasagittal portion of the longitudinal bipolar montage.

The prominent spiky activity is EMG, from frontal and temporal muscles.

EMG monitoring is most commonly used for determination of muscle tone in sleep recordings in neonates. EMG monitoring is also performed during some sleep studies for documentation of nocturnal myoclonus or other limb movements during sleep.

Respiratory Monitoring

Respiratory monitoring can be performed in a number of ways. One is by chest transducer, essentially a strain gauge around the chest recording chest excursions. Airflow can be measured by a detector near the nares, but this has a greater possibility of disturbing the patient. Airflow meters can be used on intubated patients, but this is seldom clinically indicated.

Montages and Localization

Overview

EEG is performed in a variety of montages, so EEG can be assessed with a spectrum of presentations. For example, a spike may be more visible on one montage than another. Modern digital machines have the ability to change montage while displaying the same epoch, adding extra interpretive flexibility.

Rules of Polarity

All EEG channels have two inputs. Each EEG channel represents the difference in potential between two adjacent electrodes. In referential montages (see discussion below), the active electrode is in the first input and a presumably neutral reference is in the second input. Because of this relationship, the first input has been called "active" input and second input "reference" input. However, in bipolar montages (and in the instance of an active reference), both inputs are active. By convention, a negative potential in the first input is seen as an upward deflection, whereas a positive potential in the first input is seen as a downward deflection. Potentials arising in the second input will have the reverse appearance.

Polarity convention of EEG display is as follows:

- Relative negativity at input 1—upward deflection;
- Relative negativity at input 2—downward deflection;
- Relative positivity at input 1—downward deflection;
- Relative positivity at input 2—upward deflection.

However, this elementary localization only applies if a signal is at one electrode and the other is at zero-potential, and this is seldom the case. The deflection of the display is the relative difference in potential. For example, if input 1 has a negative signal, one would expect a upward deflection, but if the field of the potential is such that input 2 has an even greater negative signal, then the deflection would be downward since input 1 is relatively positive in comparison to input 2.

So, the terms *active* and *reference* are really misnomers. For bipolar montages, adjacent electrodes are usually connected in the two inputs. By convention, for any electrode pair comprising an EEG channel, input 1 would be the electrode either anterior or on the left of the electrode connected to input 2. From this discussion, it should be evident that a positive signal of 10 µV at input 1 would produce the same display deflection as a negative signal of 10 µV at input 2.

So, the "reference" input can be just as active as the "active" input—positive 10 µV at the "reference" electrode will give the same vertical deflection of the display as negative 10 µV at the "active" electrode. The recording is an arithmetic subtraction between the "active" and "reference" electrode potentials. In the remainder of this book, we will use the terminology of *input 1*, or *first input*, and *input 2*, or *second input*.

Montages

Montages are created so that viewing the EEG gives the neurophysiologist a clear picture of the spatial distribution of EEG across the cortex (see Figure **3-10**). Because of this, many neurophysiologists have their favorite montages, though they realize that they should view multiple montages in a recording. A good montage is one that can be easily imagined and remembered. It should also have equal electrode distances within each chain (unless it includes electrodes outside the 10-20 system, such as sphenoidal electrodes).

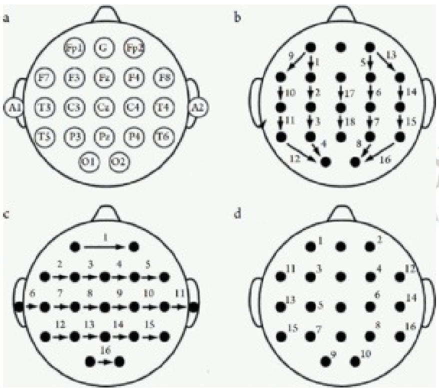

Figure 3-10:

Common montages used in clinical practice:

a: Electrode placement terminology,

b: Longitudinal bipolar,

c: Transverse bipolar,

d: Referential

The American Clinical Neurophysiology Society (2006) has published extensive guidelines for performance of EEG. These will be called the *Guidelines* for the rest of this text. The guidelines recommend the following:

- Record at least 16 channels.

- Use the full 21-electrode array of the 10-20 system.
- Both bipolar and referential montages should be used.
- Electrode connections for each channel should be clearly indicated.
- Pattern of electrode connections should be made as simple as possible and the montages easily comprehended.
- Bipolar electrode connections should run in a straight unbroken line with equal interelectrode distances.
- Display of more anterior electrodes generally should be placed above those of more posterior location.
- At least some common montages should be used between studies for ease of comparison.

In addition, some recommendations that most labs adhere to include:

- Display of left-sided electrodes generally should be placed above those of right-sided electrodes.
- Although 16 channels are considered minimum, montages should be used employing the maximum number of channels of the machine.
- Three classes of montages should be used:
- Longitudinal bipolar;
- Transverse bipolar;
- Referential.
- If sufficient channels are available, polygraphic channels are desirable. EKG is most commonly recorded, but EMG and respiratory monitoring can be of value.

Recommended montages for routine use in adults and children after the neonatal period are shown in Table 3-3. Additional channels are used when available and needed. The additional channels may be used for EKG, eye movements, respirations, or EMG.

Table 3-3 Montages in Routine EEG

Channel	*Longitudinal bipolar (LB)*	*Transverse bipolar (TB)*	*Average (Ave)*	*Reference (Ref)*	*Circumferential (Circ)*
1	Fp1–F3	Fp1–Fp2	Fp1–Ave	Fp1–A1	T3–F7
2	F3–C3	F7–F3	Fp2–Ave	Fp2–A2	F7–Fp1
3	C3–P3	F3–Fz	F3–Ave	F3–A1	Fp1–Fp2
4	C3–O1	Fz–F4	F4–Ave	F4–A2	Fp2–F8
5	Fp2–F4	F4–F8	C3–Ave	C3–A1	F8–T4
6	F4–C4	A1–T3	C4–Ave	C4–A2	T3–T5
7	C4–P4	T3–C3	P3–Ave	P3–A1	T5–O1
8	P4–O2	C3–Cz	P4–Ave	P4–A2	O1–O2
9	Fp1–F7	Cz–C4	O1–Ave	O1–A1	O2–T6
10	F7–T3	C4–T4	O2–Ave	O2–A2	T6–T4
11	T3–T5	T4–A2	F7–Ave	F7–A1	Fp1–F3
12	T5–O1	T5–P3	F8–Ave	F8–A2	F3–C3
13	Fp2–F8	P3–Pz	T3–Ave	T3–A1	C3–O1
14	F8–T4	Pz–P4	T4–Ave	T4–A2	Fp2–F4
15	T4–T6	P4–T6	T5–Ave	T5–A1	F4–C4
16	T6–O2	O1–O2	T6–Ave	T6–A2	C4–O2
17	Fz–Pz	Fz–Cz	Fz–Ave	Fz–A1	Fz–Cz
18	Cz–Pz	Cz–Pz	Cz–Ave	Cz–A1	Cz–Pz
19	EKG	EKG	Pz–Ave	Pz–A1	EKG
20			EKG	EKG	

The ipsilateral ear reference (Ipsi) can be replaced with the linked reference (LE) if there is prominent EKG artifact from one or both ear references. The EKG artifact tends to be of opposite polarity on the two sides, and linking the ears will usually attenuate it or eliminate it.

Localization

Localization of an abnormal potential depends on spatial mapping using the electrode positions and applied montages discussed above. Here, we will discuss montages and

localization in more detail. Modern EEG equipment allows for changing of montage on the fly, and allows for review of the same epoch in multiple montages for comparison. This is only part of the post-processing that can be performed on digital EEG recordings.

Referential Montages

In *referential* montages, a single reference or two references (as in linked ear reference recordings) will be in the second input of each channel, while active electrodes are in the first input. In the ideal situation where the reference is neutral, potentials of interest are compared by amplitude, the largest amplitude reflecting the center of the field. However, references are frequently not neutral, hence the importance of considering more suitable references. With digital EEG recordings, this task is facilitated, as the same potential can be examined with a variety of references. Thoughtful consideration of the most appropriate reference is necessary.

The *average reference* is derived from averaging the activity of all electrodes (except frontopolar and anterior temporal, which are subject to large eye movement artifacts). Assuming that no large field synchronous activity is present, there is cancellation based on cerebral activity being out of phase in different channels. The average reference is ideal for any focal abnormality. However, when discharges have a wide field, the average reference may become contaminated. Therefore, the average reference is not ideal for examining generalized spike-and-wave discharges and other generalized abnormalities. The ipsilateral ear reference, or linked ear reference, is optimal for evaluation of generalized discharges, which tend to have the lowest amplitude in the temporal periphery. The ear reference is not suitable for temporal lobe discharges since the ear can be considered a lateral-basal temporal electrode. It is frequently involved in temporal lobe discharges. The average reference will usually be a more appropriate reference for studying temporal lobe activity. However, if the temporal lobe activity has a wide field, the average reference could also become contaminated. Using the midline electrodes (Cz, Fz or Pz) is useful, particularly for evaluating ictal activity if the ictal discharge has not involved the midline. In particular, if the discharge field is anterior, Pz could be sufficiently distant to be neutral. In contrast, if the ictal discharge is predominately posterior, then Fz would be more appropriate. In some instances, the average reference can be manipulated to become neutral by removing affected electrodes from the average reference.

Laplacian referential montage is excellent for identifying focal gradients by using a unique reference for each electrode, weighted by surrounding electrodes. The Laplacian montage is excellent for pointing out small focal potentials with a steep gradient, but is not appropriate for displaying generalized activity.

Localization in a Referential Montage

Localization in a referential montage is dependent on amplitude, assuming the presence of a neutral reference. The channel containing the highest amplitude will represent the location at the center of the field. Unfortunately, there is no ideal reference that is always neutral. For very focal discharges, the average reference is very suitable, because the contribution of the focal discharge to the average is greatly diluted by the uninvolved electrodes.

Bipolar Montages

Bipolar montages are composed of chains linking adjacent electrodes. These chains are either longitudinal or transverse. They may also be in an arc, circle, or semicircle. The longitudinal bipolar montage (also called “double banana” because of the appearance on a montage diagram) can be organized in several ways. It is a general (but not universally followed) convention that anterior should be ahead of posterior and left ahead of right. Besides the example displayed in the table (see Table 3-3), one acceptable alternative arrangement is left temporal, left parasagittal, midline, right parasagittal, right temporal; another arrangement is left temporal, right temporal, left parasagittal, right parasagittal, midline. There are relatively fewer potential permutations in the arrangement of transverse bipolar montage.

Localization of EEG activity in bipolar montages is by reversal of polarity (see discussion below) and is optimally accomplished when the center of the field is within the center of the chain. As a result, EEG activity centered in the frontal or occipital pole is not optimally assessed by either the longitudinal bipolar or transverse bipolar montage. This is where a circumferential montage may be useful. In a circumferential montage, the frontopolar and occipital electrodes are at the center of the anterior and posterior semicircular chains.

Localization of Potentials in a Bipolar Montage

In a bipolar montage, localization is accomplished by identification of reversal of polarity. Below are several situations and the expected pattern with each.

- *Potential is present in a single electrode:* In this situation, there will be reversal of polarity between the two channels that have this electrode in common. (see Figure **3-11**)
- *Two electrodes involved, both contained within a chain of electrodes, and not involving the ends of the chain:* The channel that compares the two affected electrodes would show cancellation. The reversal of polarity will be seen across that channel. One can state that there is a reversal of polarity across a zone of equipotentiality between electrodes B and C. The two channels showing a deflection will be mirror images of each other, again with equal amplitude of opposite polarity. (see Figure **3-12**)
- *Two electrodes, unequally involved, each contained within the chain, with the ends of the chain not involved:* There will be reversal of polarity seen between the two channels that contain the most affected electrode. The potential will also be seen in the channel containing the less affected electrode and the unaffected electrode adjacent to it. The amplitude in the channel with the largest deflection will be equal to the sum of the amplitudes in the two channels with smaller deflections. From this, one can conclude that if there is a reversal of polarity that is not a mirror image, it indicates that there is involvement of more than a single electrode. (see Figure **3-13**)
- *Potential is present at the end of the chain and not involving any other electrode in the chain:* In this instance there will be no reversal of polarity. A deflection will be seen in the first (or last) channel of the chain, where the potential is contained. (see Figures **3-14** and **3-15**)
- The potential involves one end of the chain and the electrode adjacent to it, equally: There will be cancellation in the channel that contains the two affected electrodes. The channel next to it will show a deflection. There will be no deflection in subsequent channels. There will be no reversal of polarity. (see Figure **3-16**)

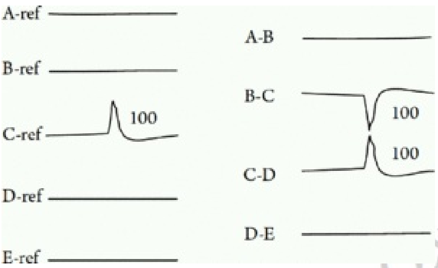

Figure 3-11:

Referential recording on the left and corresponding bipolar recording on the right. Electrode C is the only electrode affected by the discharge. The number is a measure of amplitude. The bipolar recording shows reversal of polarity at C, the electrode in common between the second and third channels on the right. Note that the B-C and C-D are mirror images, and the amplitude of the deflection is similar but of opposite polarity.

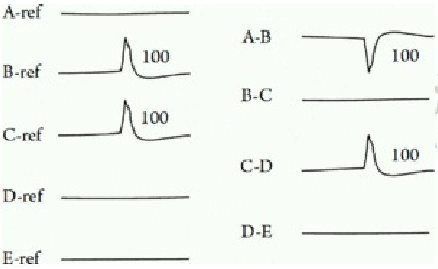

Figure 3-12:

Since electrodes B and C are equally affected, the difference between them is 0, hence the flat line. There is a reversal of polarity across a zone of equipotentiality between B and C. B and C are equipotential, i.e., equally affected.

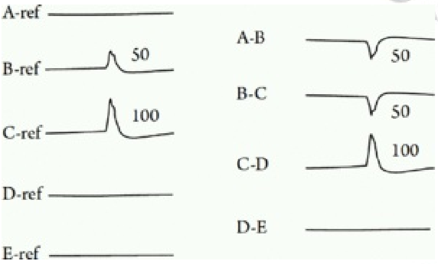

Figure 3-13:

This illustrates how EEG is an arithmetic operation. The reversal of polarity at C indicates that the highest voltage is at C. The finding of a lower amplitude at B-C than C-D suggests that there is involvement of B.

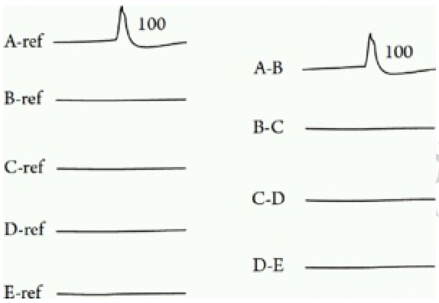

Figure 3-14:

End of chain phenomenon. The potential originates in the anterior end of the chain.

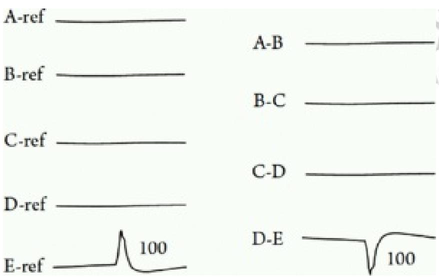

Figure 3-15:

End of chain phenomenon. The potential originates in the posterior end of the chain.

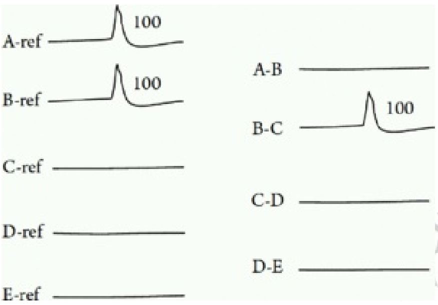

Figure 3-16:

The source leads have equal potentials at the end of chain. Therefore, the bipolar montage shows a response that might not be obviously end-of-chain..

Figures **3-11** through **3-16** show simulated recordings associated with the localization examples just discussed.

Every pattern in a bipolar montage has several potential solutions in a referential montage, assuming a neutral reference. Usually, one solution is the most likely.

Consider Figures **3-17** and **3-18** together. The left side of each figure is a bipolar recording that is identical. The right is a potential referential recording that could correspond to the bipolar recording.

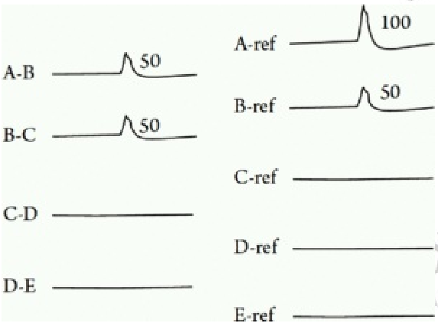

Figure 3-17:

Left: bipolar recording, Right: referential recording of same potential.

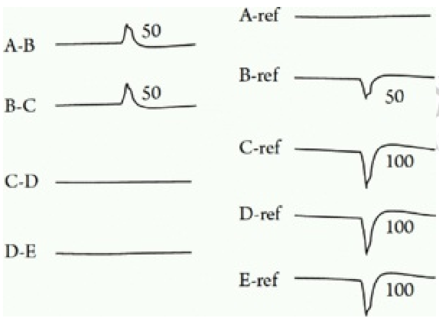

Figure 3-18:

Left: bipolar recording.Right: referential recording of the same potential.

Which of these two possibilities is most likely? In these examples, the distribution shown in Figure **3-18** is less likely than that of Figure **3-17**, because the Figure **3-18** distribution assumes that three electrodes are all equally affected, an unlikely distribution.

Although a bipolar montage can be used to suspect asymmetries in widespread activity, these asymmetries have to be confirmed in a referential montage. The main reason for this is that each bipolar channel is an arithmetic subtraction of adjacent active electrodes. There will be a low amplitude if adjacent electrodes are equally affected. The presence of a high amplitude signal depends on a sharp gradient between adjacent electrodes. Fortunately, most potentials have the highest gradients near the center of the field, but this is not always the case. An electrical bridge due to electrode paste smear will produce a very low amplitude that could be misinterpreted as attenuation of activity in that region. The examples in Figures **3-19**, **3-20**, and **3-21** illustrate these concepts.

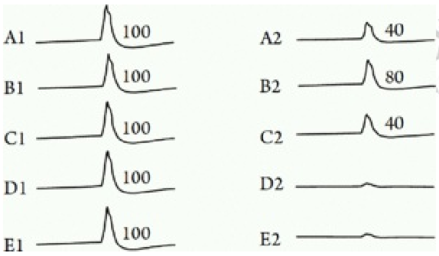

Figure 3-19:

Referential recording. To the left are left electrodes and to the right are right-sided electrodes. Figure **3-20** is the bipolar recording corresponding to the above referential montage.

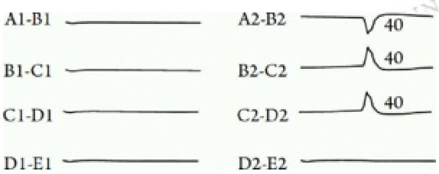

Figure 3-20:

Compare with Figure **3-19**. The bipolar derivations might suggest that the discharge is not seen on the left. This shows how asymmetries must be confirmed in a referential montage before definitive interpretation.

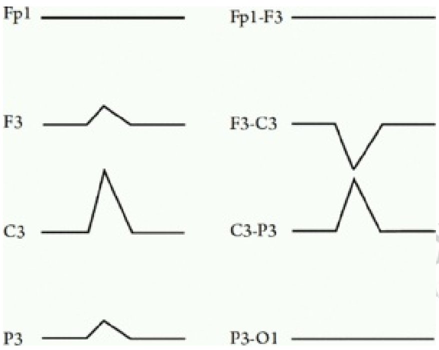

Figure 3-21:

Left: A referential montage is used where the reference is over an inactive area. The sharp wave has a maximum at C3 but the field can be seen at F3 and P3. FP1 and O1 (not shown) are not in the field of the sharp wave.

Right: Bipolar montage, the left parasagittal portion of the longitudinal bipolar montage.

Special Considerations

Average versus Ear Reference: Contamination of the Average

Many laboratories use average montages with few ear-reference montages; however, there are some special considerations when the average is contaminated by activity prominent in the record. The example in Figure **3-22** shows the posterior dominant alpha, which is clear in the right side of the figure in this ear reference epoch.

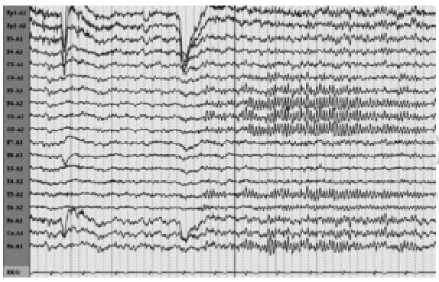

Figure 3-22:

Prominent alpha especially seen on the right side of this figure.

Figure **3-23** is of the same epoch but with an average reference. The posterior dominant rhythm is evident, but has a field that extends outside of the occipital area. This rhythm may not appear to be the PDR, but is so since the native rhythm contaminates the average. Leads without the PDR show the rhythm well.

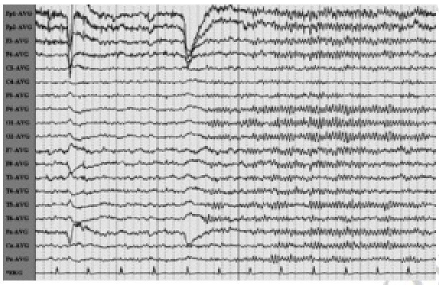

Figure 3-23:

Same epoch as the above figure but with average reference, the field is more extensive than with the ear reference because the posterior rhythm contaminates the average.

End of Chain Phenomenon

Bipolar montage may have difficulty in localizing discharges at the end of the electrode chain, as was illustrated in the diagrammatic examples above. Figures **3-24** through **3-26** show this for a real patient. For the LB montage, this end of chain phenomenon is at the frontopolar and occipital regions. In the TB montage, the end of chain affects especially the temporal region.

Figure 3-24:

Right frontal discharge but precise localization is difficult.

Figure 3-25:

Same discharge but better localization with an ear reference montage.

Figure 3-26:

Bipolar montage across the front is best able to map the discharge.

The patient recorded in Figure **3-24** has a right frontal discharge that is seen on LB montage, but precise localization is difficult. Ear-reference montage for the same epoch (Figure **3-25**) shows better localization. Bipolar montage across the frontal region (Figure **3-26**) is best able to localize the discharge.

Running the Test

Initiation of the Test

Patient Identification and Study Verification

The patient is identified just as for any hospital or office procedure, using clinic or hospital documentation, arm-band if available, and check-in ID if not.

The study is also verified, since it is possible that the wrong study has been scheduled. The technician can verify the study intent by review of the office of hospital records pertaining to the study, particularly the designation of indication.

So the technician needs to verify the following:

- Identity of the patient;
- Correctness of the study;
- Particulars of the study so that the clinical question can best be answered.

On the recording as sent to the reading physician, the following information needs to be attached.

- Name;
- Age;
- Identification number of the patient;
- Index number of the recording;
- Time and date of the recording;
- Clinical reason for the study;
- Time of the last seizure, if appropriate;
- Ordering clinician;
- Current medications;
- Sedative medications used;
- Name of the technician;
- Technical summary, including activation methods and artifacts;
- Technician's observations, including regions of particular interest.

Pretest Calibration and Testing

Pretest calibration and testing should be fairly standard and includes the components discussed below. The study reader should review the results of this calibration and testing since errors are not always noticed by the technician and errors can have significant effects on interpretation.

Impedance Testing

Electrode impedance should be at least 100 ohms and usually no more than 5 kohm. Sometimes, impedance cannot be kept within this window, so if the impedance has to be higher than 5 kohm, then the impedance should at least be approximately equal for the electrodes. Excessively high impedance indicates that there is a problem with the leads or fixation of the leads to the scalp. High electrode impedance increases noise.

Excessively low impedance usually indicates smear between the electrodes, and would impair visualization of electrocerebral potentials. When two electrodes are electrically connected by conductive gel/paste, they act as a single large electrode. Even in referential recordings they are a problem, limiting the sharpness of localization.

Square-wave Calibration

Square-wave calibration (see Figure **3-27**) produces a typical appearance that can be compared visually from channel to channel. One or more channels that have distorted waves from square-wave calibration are an indication of either errant settings or equipment failure. Square-wave calibration is performed before and after the study.

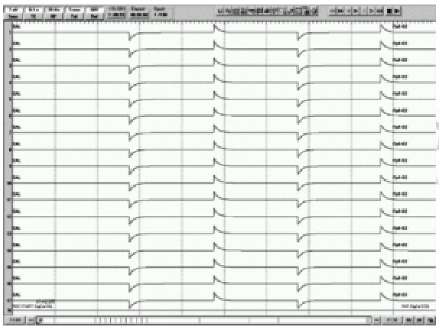

Figure 3-27:

Square wave calibration performed prior to a study.

A square-wave pulse is delivered from a waveform generator into each amplifier input. This pulse is 50µV in amplitude and is alternated on and off at 1 second intervals. The wave does not appear precisely square because of the effects of the preset default filters.

The low-frequency filter (LFF) transforms the plateau of the signal pulse into an exponential decay. The rapidity of the decay depends on the filter setting. The lower frequency the setting, the slower the decay. Higher settings of the LFF cause the decay to baseline to occur rapidly.

The high-frequency filter (HFF) rounds off the top of the peak of the calibration recording. Lower settings of the HFF cause the peak to be blunted and of lower amplitude. Higher settings of the HFF cause the peak to be sharper and of higher amplitude.

We recommend trying different filter settings while recording square-wave calibration. The experienced neurophysiologist can determine an error in response of the system by abnormalities in the square-wave calibration. Some of these abnormalities include:

- Peak too rounded;
- Peak overshoot;
- Incorrect rate of decay;
- Too low or too high amplitude of the signal.

These determinations are made in comparison with other recordings and in comparison to the recordings from the other channels.

Bio-calibration

Biological calibration (bio-calibration, or Biocal) assesses response of the amplifiers and filters to a complex biological signal, composed of a host of frequencies. In the days of paper recordings, the montage Fp1-O2 was used for every channel, testing the integrity of the amplification system. Nowadays, digital equipment provides each channel with its own amplifier, so Biocal can be each electrode against a common reference or the traditional Fp1-O2. (Figure **3-28**)

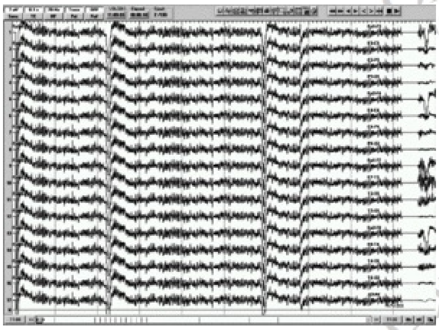

Figure 3-28:

Biocal performed prior to a study. Same patient as in Figure **3-27**.

The technician and reader should review the Biocal for unexpected differences in amplitudes or frequency responses.

Integrity of the System

Integrity of the system is checked especially for studies where there is such little signal that the recording system error has to be considered. Brain death and severe encephalopathy can produce recordings that are almost flat. So to test the integrity of the system, the technician touches the electrodes and the artifact is readily visible. Representative electrodes need to be touched, not necessarily each one.

Montage Selection

Modern digital EEG allows for montage selection by the interpreting physician rather than use of predetermined montages during recording. This way, technicians do not have to be as attentive to the specific wishes of the anticipated reader during acquisition. Most of us use a combination of longitudinal bipolar, transverse bipolar, and referential montages during reading. A particular wave of interest can be reviewed in multiple montages, which can greatly help localization, but we must not fall into the trap of believing that different visualizations of the same transient are multiple occurrences of a transient.

Montages with vertex or ear reference are used less than in the past, mostly because of prominent electrocerebral activity of these electrodes making them imperfect references.

During recording, the technicians typically also select a variety of montages, except during prolonged recordings, so they can identify potentials of interest to bring to the attention of the readers.

Filters

Standard low-frequency filter (LFF) setting for routine EEG is 1 Hz. This corresponds to a time constant (TC) of 0.16 sec. If the LFF is set higher, there is distortion and attenuation of some slow waves. The waves can have an increased number of phases and seem to be composed of faster frequencies. The technicians should be discouraged from turning up the LFF when there is an abundance of slow activity. The low frequency filter setting can be adjusted downward to improve the identification of suspected slow activity.

Standard high-frequency filter (HFF) setting for routine EEG is 70 Hz. This is slightly higher than line power frequency. Therefore, turning the HFF to a lower frequency will attenuate electrical artifact; however, this should be discouraged, because this will also attenuate physiological sharp activity.

The 60-Hertz or “Notch” filter attenuates specifically line power, 60-Hz in the United States and Canada and 50-Hz in the United Kingdom. The 60-Hz filter is not needed for most patients in office practice, because the office laboratories are electrically protected. However, in a hospital or especially ICU setting, the filter may be required in order for line artifact to not obscure the recording. The filter should not be used to correct focal 60-Hz artifact, which is most likely related to focally increased electrode impedance. Focal 60-Hz artifact should prompt the technologist to perform an electrode impedance check and correct electrode impedances.

Digital filters accomplish the same tasks as analog filters, and are essentially calculations performed on the arrays of data.

Sensitivities

Amplifier sensitivity is initially set to 7 µV/mm. Increased sensitivity is used with low-voltage recordings, most common in elderly patients in the awake state, and in pathological states of electrocerebral suppression. The sensitivity is increased to 2 µV/mm for brain death studies. Reduced sensitivity is used for patients with high-voltage EEGs, such as in children, especially in the sleeping state, and when there are high amplitude transients such as seizure discharges.

Sensitivities on reading need to be selected with care. Reduction in sensitivity to better view a high-amplitude event may make lower-amplitude components invisible, such as a small spike component or notch. This effect is especially notable with seizure discharges—a reduction in sensitivity to view the discharges may appear to accentuate

postictal suppression because the sensitivity is not returned to default levels.

Display Time and Page Rate

The concept of *display time* is new to digital recordings. Traditional paper EEG recordings used a paper speed of 30 mm/sec; this gave an x-axis resolution that allowed for adequate visual interpretation of the spectrum of frequencies of routine EEG, just as the standard sensitivities gave a y-axis scale that allowed for detection of most of the range of EEG amplitudes. Digital displays depend on resolution of the monitors, graphics cards, and acquisition and review software, but in general, the display time is adjusted so that the display looks roughly similar to a paper display. For a typical 19" monitor, this means display of approximately 10 seconds of EEG on one screen, with part of the display taken up by other data elements. But since display sizes are not standard, we cannot give fixed recommendations on display time.

Display time may be altered in a few circumstances. Display time can be shortened substantially if the reader is comparing timings with very short differences (e.g. spike onset from one hemisphere or the other). Display time can be lengthened if the reader is concentrating on EEG features such as sleep stage, where overview of much longer times is warranted.

Page rate is the rate at which the pages change. If we were to change pages at a rate concordant with the number of seconds displayed on the screen, the study would be reviewed at native speed. Reviewing each EEG at acquisition real-time speed would be impossible for most of us, so we page through digital EEGs faster than acquisition. Many readers review the EEGs at approximately twice acquisition speed. Faster speeds than this may increase the risk of missing transients or other subtle abnormalities. We are also commonly stepping back in study time to replay an event or region of interest, often with a change in montage and/or sensitivity.

Annotation

Important events must be noted using annotations that are available on all modern EEG devices. Technicians need to be familiar with how to create and edit annotations and must know the preferences on the part of the reading physicians for documentation of annotation.

Among the observations that should be noted are:

- Apparent state changes;
- Beginning and ending of activation procedures and comments about the performance, e.g. good effort on hyperventilation or not;
- Clinical events that might be seizures. The technician will likely note the beginning and ending and later will have to create more detailed notes about the event, appearance, etc.
- Response to stimuli from the technician. Our technicians usually assess responsiveness with a spectrum of stimuli ranging from sternal rub to questions assessing mental status.
- EEG findings that the technician has noted and wants to bring to particular attention of the reading physician.
- Artifacts identified by the technician and noted at least the first time or two, e.g. ventilator, IV pump, or other artifact of the ICU. Similarly, electrical transients that are typical of a medical setting, such as nearby machinery turning on and off, should be noted if visible to the technician on the record.

Patient Behaviors during the Test

As part of the annotation, patient behaviors are documented, so even if the study does not include a video component, the reading physician knows the clinical observations. For example, a low voltage fast background has different implications in an unresponsive patient versus one who is awake.

Clinical seizures are described in detail in the annotations, including onset and offset. Not only is a description of the seizure itself important, but also the postictal period. This is of particular use in differentiating epileptic seizures from non-epileptic events.

Movement artifact deserves a description in the technician’s annotations (e.g., tremor or dyskinesias versus agitated delirium versus clinical seizures).

Testing Patients during Events

Stimulation

Technicians assess the responsiveness and mental status of the patient during the study. For awake patients, this usually includes noting the response to questions such as name and location, and some additional cognitive responses (e.g., “Name a red fruit”).

For encephalopathic patients, responses to verbal stimuli are noted, as are responses to tactile stimulation if there is no response to verbal stimulation. For severe encephalopathy and coma, response to sternal rub or similar is essential. The annotation of the stimulus not only allows the reading physician to know when an alerting response might happen but also lessens the likelihood that the mechano-electric response from the stimulus might be misinterpreted as electro-cerebral response.

Provocation of Seizures

Provocation of seizures by means other than activation methods is controversial to some clinicians, since they might see this as intellectually dishonest when used to elicit non-epileptic seizures. However, this is an important tool to help diagnose epileptic as well as non-epileptic events, and the diagnostic yield certainly justifies the procedure in select circumstances. The implications of event misdiagnosis can be much more important.

Mechanisms to provoke seizures include:

- Asking the patient what provokes the event, then re-creating that as best as possible in the lab; for example, standing quickly, eating or drinking, and listening to particular music have been described by patients as evoking clinical seizures, and these were all tested in our laboratory during EEG recording.
- Induction techniques such as hyperventilation and photic stimulation, which can trigger epileptic seizures, can also be used to trigger non-epileptic events. Suggestion can also be used, though deception should generally be avoided in clinical practice.
- The technician might remark that signs of an impending seizure are appearing. While a clinical event in response to suggestion does not rule out genuine epileptic events, this does at least make the argument for a psychological component and favor non-epileptic events. The use of suggestion is controversial.
- Some laboratories have used injections of intravenous saline to induce clinical seizures, but this is done rarely and then only under rigorous conditions. This should be used as a last resort for diagnosis, if ever.

Activation Procedures

Photic Stimulation

Photic stimulation is produced by a bright strobe, which is placed in front of the patient with the eyes closed. The flashes are bright enough to illuminate the retina even through closed eye lids.

The stimulation protocols are programmed into most modern EEG machines, but one typical protocol is the following:

- Train duration of 10 seconds;
- Interval between trains of 10 seconds;
- Initial flash rate of 3/sec.

Higher flash rates are subsequently delivered up to 30/sec.

Abnormal EEG activity elicited by a specific frequency should be identified by the technologist, and subsequently that particular frequency should be repeated at the end of the photic stimulation session, to verify that the response was not coincidental.

For safety reasons, it is not advisable to precipitate a full-fledged generalized tonic-clonic seizure with photic stimulation. If a clear photoparoxysmal response appears, the technologist should abort the stimulation train before a seizure develops. If a consistent photoparoxysmal response is noted at two to three consecutive frequencies, then stimulation can be resumed from the highest frequency to establish the upper limit of the photosensitivity frequency range.

Hyperventilation

Hyperventilation is performed for 3 minutes on routine testing, and should be performed for 5 minutes if there is strong suspicion of absence epilepsy. Hyperventilation is often not performed in elderly patients for fear of resultant vasospasm and impaired cerebral perfusion, but at the time of this writing, we are unaware of good data proving high risk.

The normal response to hyperventilation is diffuse slowing with the appearance of theta range activity. The slowing is of higher amplitude in children than adults. Hypoglycemia augments the slowing.

Hyperventilation is used predominantly to active the 3-per-second spike-and-wave discharge of absence epilepsy. In some patients, the discharges are only seen during hyperventilation.

Sleep Deprivation

Sleep deprivation increases the possibility of seeing epileptiform activity, and therefore is used for patients in whom routine EEG has not been able to identify interictal epileptiform activity. Although sleep is attempted in most EEG studies for epilepsy, sleep deprivation is still considered a physiologic activation method.

Artifact Identification and Management

Artifacts are discussed in detail, but in general, the technician should note not only epileptiform and response events on the record but also sources of potential artifact. Some of the common artifacts that deserve annotation on the record include:

- Swallowing;
- Chewing;
- Talking;
- IV pump;
- Ventilator;
- Nurse working with patient;
- Tremor;
- Other patient movement.

This list is not comprehensive, but is representative of the types of artifacts the technician should note.

Termination of the Test

Post-procedure Calibration

Calibration after the procedure is similar to the pre-procedure calibration. This should be routine and include all of the elements of pre-procedure calibration.

Documentation

The technician’s worksheet is paper or digital equivalent and contains most of the information required for the reader to interpret the test. Limitations of these data makes the reader occasionally need to review the electronic medical record, but good preparative data should allow this to be minimized.

The physician’s report can be dictated or electronically generated but should be created in a timely fashion. We require outpatient studies to be read within 24 hours of completion, and inpatient recordings should be interpreted as soon as possible so that critical abnormalities are addressed.

Storage and Archive

Modern digital EEGs are much easier to store than older paper records, which had to be microfilmed. Storage is usually on optical disc for archive with recordings kept on the computers for a variable length of time. We recommend maintaining a record available for on-demand online viewing at least until the physicians have reviewed the record and seen that patient. For hospitalized patients who may have a series of recordings, maintaining the recordings online for as long as the patient is in the hospital is warranted.

Archive is through a number of mechanisms, and many facilities keep two copies, one local and one remote. This is similar to data handling of patients’ electronic medical records.

Routine EEG Review

Overview

EEG performance and interpretation should be a systematic process, with the following elements:

- Understand the clinical snapshot of the patient, including reason for the study, age, and conditions that affect interpretation.
- Review the study for background patterns in the context of state.
- Look for transients and rhythms that may be abnormal.

- Assess response to stimulation and activation methods.
- Look for changes in state.
- Synthesize an impression that places the EEG findings in the context of the clinical snapshot.

This section discusses some specifics of the basic interpretation of EEG.

EEG Analysis

Terminology

Rhythmic: term used to describe ongoing EEG activity composed of recurring waves of equal duration. The waves need not be identical, but they usually resemble each other. Cerebral activity is never perfect, and slight variation should be allowed. For example, the activity in Figure **3-29** is rhythmic, but some individual waves are slightly shorter or longer than others, as demonstrated in Figure **3-30**.

Figure 3-29:

The background wave has a frequency as indicated by the vertical lines. Although there is variation in wave-period, there is an average frequency that described this rhythm.

Figure 3-30:

This rhythm is regular. Although there is some variation in amplitude and appearance, the rhythm has uniform period.

Rhythm: EEG activity composed of recurring waves of equal duration. A rhythm is often characterized by its frequency.

Frequency: the number of waves of a specified rhythm per second, or 1/wavelength. Frequency is measured in Hertz or Hz, meaning cycles per second. Wavelength is measured in milliseconds or seconds. Frequency can be applied to single waves as well as to a rhythm. If applied to a single wave, inferred frequency is 1/wavelength. Most digital EEG manufacturers will provide automatic calculation of frequency by marking the margins of a wave. For a rhythm, the frequency will express how many waves will fit in one second. In the example, nine waves can be counted between the two 1-second lines (Figure **3-30**). The frequency can also be derived with the formula: frequency = 1/wavelength. The duration of the average wave is 111 msec or 0.111 sec. The frequency is 1/0.111= 9 Hz. For frequency determination of fast activity, the measurement can be made more reliably by counting waves contained in one second, because of slight variation in wavelength duration.

Regular: applies to activity that is uniform, with individual waves having fairly consistent shape, in addition to fairly consistent duration. Thus activity that is regular will also be rhythmic. Most rhythmic activity will also be regular. This is sometimes referred to as "monomorphic."

Irregular: activity that is not uniform (see Figure **3-31**). It is in theory possible for rhythmic activity to be irregular, but that is uncommon.

Figure 3-31:

This rhythm is irregular. Although visual inspection shows a rhythm, the pattern is irregular and a uniform frequency cannot be counted.

Arrhythmic: term used to describe ongoing EEG activity composed of waves of unequal duration. Figure **3-32** shows an example of arrhythmic activity. In this activity, individual wave components have differing wavelengths. Arrhythmic activity is also irregular. Note that individual waves not only have unequal duration, but also unequal shape and unequal amplitude. This is often called "polymorphic."

Figure 3-32:

Arrhythmic activity consists of activity that does not have an apparent rhythm.

This differs from irregular in that there is no apparent rhythm on visual inspection.

Activity such as shown in Figure **3-32** can be continuous or intermittent. If the activity is intermittent, it can be described as rare, occasional, moderately frequent, very frequent, or almost continuous. However, it may be most useful to indicate the estimated percentage of time that the activity is present.

Transient: a wave or combination of waves that stands out from the surrounding background. A transient can be normal or abnormal.

Complex: combination of 2 or more waves. This combination will usually be consistent when the complex recurs. Figures **3-33** and **3-34** show a polyspike-and-wave complex that includes a series of 3 spikes followed by a high voltage slow wave. Figures **3-35** and **3-36** show a series of spike-and-wave complexes, demonstrating that complexes look fairly consistent when they recur.

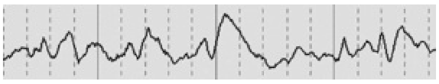

Figure 3-33:

A complex is a combination of two or more waves,

The fast polyspike complex has a following slow wave.

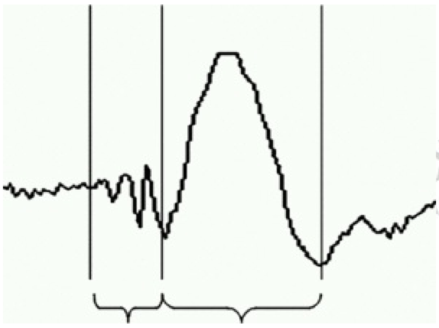

Figure 3-34:

This is the same complex shown in Figure **3-33**, but the complex is divided by the vertical markers into fundamental components.

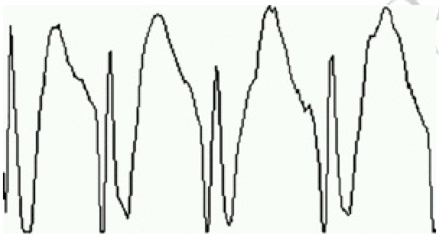

Figure 3-35:

This is a classic appearance of a spike-and-wave complex,

Well-formed spikes and associated slow waves.

Figure 3-36:

This is a less-typical spike-and-wave complex,

The spike component is small and riding on the end of the previous slow wave.

Periodic: term used to describe transients or complexes that recur, but with intervening activity between them. The rate of recurrence of periodic transients is less than the “frequency” of this transient, determined as 1/wavelength. Figure **3-37** demonstrates the difference between rhythmic and periodic discharges. The bottom line shows a single

transient. The top line shows the same transient recurring as a periodic discharge. The middle line shows the same transient recurring as a rhythmic train.

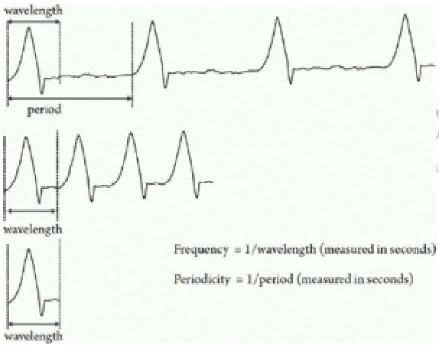

Figure 3-37:

Differentiation of a periodic pattern from a rhythm. The period is the time from the beginning of one discharge to the beginning of the next. The wavelength is the duration of the discharge. A periodic pattern has a period longer than the wavelength. A rhythmic pattern has a wavelength that is immediately followed by the next wave.

Spatial distribution. The electrodes involved with a discharge and the degree of their involvement determines the field. Discharges can be described as focal, regional, lateralized, or generalized. Focal discharges are restricted to a few electrodes on one side. The term *regional* can be applied to a discharge that involves more than a few electrodes. If electrodes on one side are all affected, the discharge can be considered lateralized. *Generalized* discharges affect all electrodes, on both sides. It is almost never the case that all electrodes are affected equally. Many generalized discharges have voltage predominance anteriorly, but there can be voltage predominance in a variety of regions. The terms *diffuse* and *widespread* are sometimes used synonymously with *generalized*, but generally indicate a less clearly generalized field. For focal and regional discharges, a field can be designated with isopotential lines that join equally affected regions. Figure **3-38** shows an example of a field. The center of the field is at F3, then C3 is a bit less involved, followed by Fp1 and F7, then Fz and Cz.

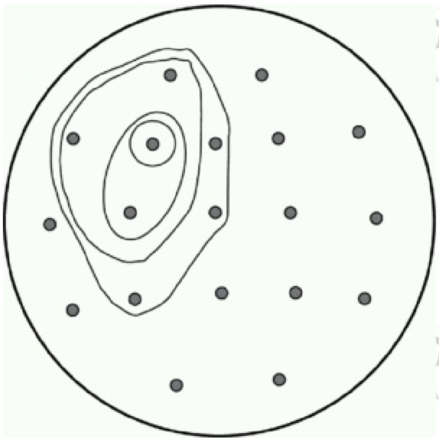

Figure 3-38:

Spatial distribution of a potential is represented on this computer presentation.

This is a standard view of the scalp, and the lines represent potential isobars.

When discharges are seen in several locations, then the temporal relationship of the activity in these different regions can be described with the following terms:

Synchronous: occurring in two regions simultaneously. To indicate that a discharge is occurring on the two sides simultaneously, the terms *bisynchronous* or *bilaterally synchronous* are frequently used. Figure **3-39** shows a bilaterally synchronous spike-and-wave discharge. It is easiest to see how the spikes are simultaneous on the two sides.

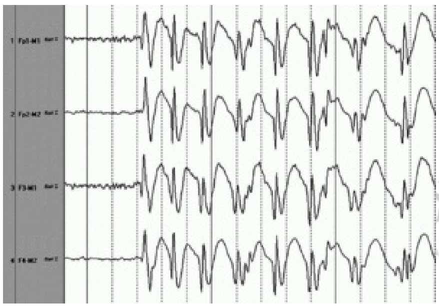

Figure 3-39:

The 1st and 3rd lines are from the left hemisphere and the 2nd and 4th are from the right hemisphere.

The spike-wave pattern is synchronous.

Asynchronous: describes transients or other activity that is seen in several regions, but not simultaneously. *Independent* is often applied to a more extreme situation where discharges occur at different times in two or more regions, or on the two sides. The circled discharges in Figure **3-40** are occurring independently on the two sides and in different regions on the same side. The tracing in Figure **3-41** shows both independent and bisynchronous discharges.

Figure 3-40:

This shows independent discharges from the left and right hemispheres, which are circled in red.

Line 3 is from the left hemisphere and line 4 is from the right hemisphere.

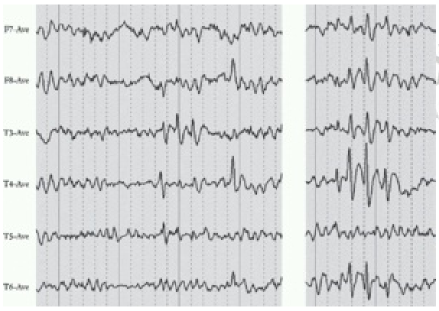

Figure 3-41:

The left side shows independent discharges, whereas the right side shows bisynchronous discharges in the same patient.

Synchronous activity can be *in phase*, indicating a perfect correspondence in time, or *out of phase*, indicating a small delay on one side in comparison with the other. When there is a horizontal dipole, with negativity in one region and positivity in another, the discharge is out of phase in these two regions.

Basic EEG Analysis

EEG analysis consists of analysis of rhythms and characterization of transients. EEG rhythms are divided into four frequency bands for descriptive purposes (see Table 3-4). Each rhythm is not specifically normal or abnormal, but the interpretation depends on the context. For example, alpha activity in the occipital region is normal in an awake patient with eyes closed. The same frequency of activity is very abnormal when diffusely distributed in a comatose patient.

Table 3-4 EEG Rhythms

Rhythm	***Frequency***	***Features***
Alpha	8–13 Hz	Waking posterior rhythm in older children and adults. Mu rhythm. Alpha coma. Seizure activity in the alpha range.
Beta	> 13 Hz	Drowsiness in children. Drug-induced. Breach rhythm over a skull defect. Seizure onset in the beta range.
Theta	4–7 Hz	Drowsiness, young children; temporal theta in the elderly. Structural lesion. Encephalopathy.
Delta	< 4 Hz	Sleep, posterior slow waves of youth. Focal structural lesion. Encephalopathy.

Transients can also be normal or abnormal depending on character and context. For example, multifocal sharp transients in a neonate can be normal but are distinctly abnormal in an older child or adult.

Fundamental Frequency Bands

Alpha

Alpha rhythm is 8–13 Hz. It is most commonly seen in normal patients from the occipital regions in the awake state with eyes closed. When the eyes open, the alpha rhythm is attenuated. Because the occipital rhythm is in the alpha range, the term *alpha rhythm* is sometimes used for the posterior dominant rhythm, but this is not preferred. Therefore, one needs to keep in mind the potentially confusing dual use of this term. There are other EEG activities in the alpha range: the *mu rhythm*, which is the resting rhythm of the rolandic region, and the *third rhythm*, which is seen at times in the temporal region.

Beta

Beta rhythm is greater than 13 Hz, and is most often seen in patients who have been sedated with benzodiazepines and barbiturates. The beta component of the rhythm

should be commented on during interpretation of the record, and an association with concurrent medications should be considered. However, beta can be abnormal, so the rhythm cannot be overlooked.

Theta

Theta rhythm is 4–7.9 Hz and is seen most commonly in normal drowsiness and in children. Theta in normal children makes determination of subtle encephalopathy difficult. Theta is most likely to be abnormal if it is the posterior dominant rhythm in a waking adult, or if it is focal.

Delta

Delta activity is less than 4 Hz, and is most commonly seen in sleep. There is a gradual increase in the amount of delta activity as the patient progresses from stage 2 to stage 3 and stage 4 sleep. Focal delta activity develops in patients with focal structural lesions, and a variable and unusual appearance is called *polymorphic delta activity*. Rhythmic anterior or posterior delta activity can be seen in patients with diffuse or metabolic disorders, as frontal intermittent rhythmic delta activity (FIRDA) or occipital intermittent rhythmic delta activity (OIRDA).

Transients

Spikes and Sharp Waves

Spikes and *sharp waves* are the terms used when sharp transients are determined to be abnormal and suggestive of epilepsy. Spikes and sharp waves are also referred to as *interictal epileptiform discharges or activity*. Spikes have a duration of less than 70 msec, and sharp waves have a duration of 70–200 msec, therefore appearing less sharp than spikes. Combinations of spikes, sharp waves, and slow waves are also epileptiform discharges (see Table 3-5).

Table 3-5 Epileptiform Transients

Transient	***Duration***	***Variants***
Spike	25–70 msec	Spike-and-wave complexPolyspike complexPolyspike-and-wave complex
Sharp wave	70–200 msec	Sharp-and-slow wave complex
Sharply-contoured slow wave (strictly not epileptiform)	> 200 msec	Can be isolated or with a triphasic appearance.

Spikes and sharp waves generated at the crown of a gyrus are usually surface negative, with the positive end of the dipole deep to the cortex. However, some spike foci have a horizontal dipole, where both the positive and negative poles are seen on surface recordings. One notable example is Rolandic epilepsy, in which the positive end of the dipole can be seen anteriorly. This is discussed in greater detail in Chapter 4.

There are a number of features that distinguish spikes and sharp waves from non-epileptiform sharp transients. Epileptiform discharges are different from the surrounding activity. They tend to be of high voltage; they are usually asymmetrical with a longer and larger second half in comparison with the first half; they tend to have more than one phase; and they tend to have an after-going slow wave (see Figure **3-42**). In addition, epileptiform discharges are more convincing if they arise from an abnormal background. Epileptiform discharges should be different from normal sharp activity (such as vertex waves) in their fields and in the states of arousal of the patient. The features of the spike and slow wave are compared between discharges, as an aid to localization and characterization, and clear differentiation from normal activity.

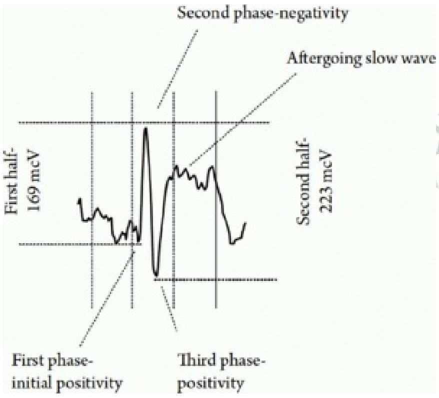

Figure 3-42:

The features of the spike and slow wave are compared between discharges, as an aid to localization and characterization.

Figure **3-42** shows some of the elements of an epileptiform discharge. These include high voltage, asymmetrical shape, more than one phase, and after-going slow wave.

Spike-like potentials that are normal are frequently a source of over-interpretation. Sharp potentials that are often over-interpreted include sharp physiologic activity, such as is seen with skull defects, EMG potentials, and artifact. Differentiation of spikes and sharp waves from non-epileptiform potentials may also take into consideration the consistency of appearance of epileptiform discharges. Figure **3-43** shows a non-epileptiform sharp activity that looks symmetrical and is similar to surrounding activity except for higher amplitude and sharpness.

Figure 3-43:

Non-epileptiform potentials resembling spikes.

Figure **3-44** demonstrates lateral rectus spikes, EMG potentials from the lateral rectus that could be misinterpreted as epileptiform discharges. Epileptiform discharges do not consistently indicate epilepsy. Caution should be used in the interpretation of pediatric EEGs with occipital or rolandic sharp waves. Caution should also be exercised in the final interpretation if only a single spike is recorded during the entire EEG. Figures **3-45** through **3-49** show examples of spikes and sharp waves.

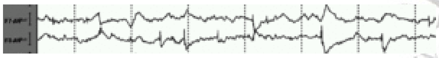

Figure 3-44:

Spikes from action of the lateral rectus resembling cerebral spikes.

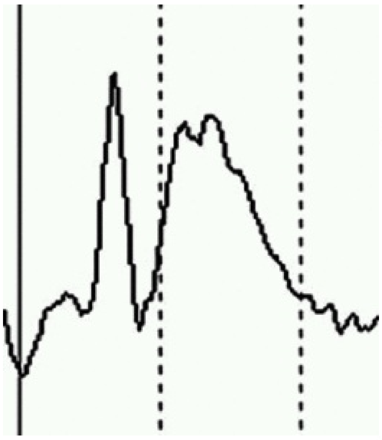

Figure 3-45:

The fast polyspike complex has a following slow wave. The duration of the above discharge is 69 milliseconds. It therefore qualifies as a spike. The dotted vertical lines are 200 millisecond lines.

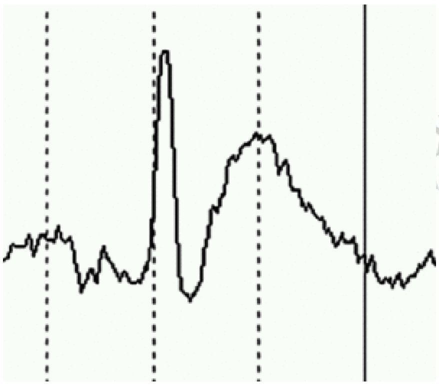

Figure 3-46:

The duration of this wave is 95 msec, so this is a sharp wave.

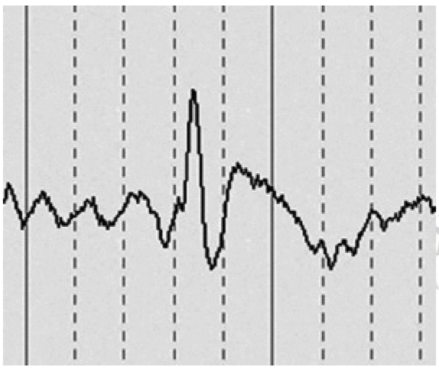

Figure 3-47:

Sharp wave without an associated slow wave. Even though it has small slow wave, it is not called a sharp-and-slow-wave complex unless the slow wave has a high amplitude (often higher than the sharp wave).

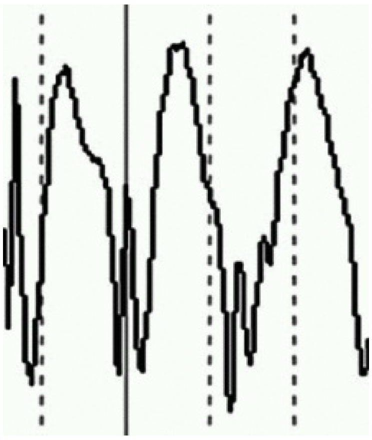

Figure 3-48:

Repetitive spike-wave complexes.

Figure 3-49:

Polyspike and wave complex.

Sharply Contoured Slow Waves

These are transients that could have been sharp waves had they not been longer that 200 msec. Such discharges have a weaker association with epilepsy and should not be called epileptiform.

Slow Waves

Slow wave transients can be in the theta or delta range and stand out from the background (see Table 3-5). Focal slow transients can be a sign of focal central nervous system (CNS) damage or reversible dysfunction (see Chapter 1). Focal slow activity can occasionally be the only abnormality seen in association with focal epilepsy.

Clinical Analysis and Interpretation

Review of Routine EEG

Some neurophysiologists begin with review of the EEG before any of the clinical information is reviewed. However, most of us prefer to know the clinical details, including the age of the patient, reason for the study, current medications, and technician's impression of the state.

Review includes determination of the following:

- Background rhythm;
- Topographical organization of the background activities;
- Transients;
- State changes;
- Response to activation methods;

Particular attention is paid to the following:

- Ictal activity;
- Sharp waves or spikes;
- Focal and generalized slow activity;
- Inappropriate response to stimuli;
- EEG correlates to changes in state or behavior.

It is often best to proceed with one uninterrupted rapid review of the recording before returning to it for a more detailed and in-depth assessment. The reason for this is that there may be a prominent abnormality later in the recording that would alter the approach to the interpretation of the preceding part of the study.

Review of Video EEG

Video EEG is initially reviewed by the technician. It is unrealistic for the neurophysiologist to review every second of the video EEG, but the epochs reviewed include the ones thought to be of interest to the technician and ones that were noted by the event marker. In our institution, a spike and seizure detection program identifies suspected seizures as well as spikes and sharp waves. In addition, the patient and patient's family are instructed to push an event marker button, which leaves a mark on the EEG recording. The technologist reviews all the patient events and computer seizure detections, and marks all the seizures, as well as suspected ictal discharges. The electroencephalographer reviews these segments first, analyzing both the EEG discharges and the clinical seizure semiology. In addition, the electroencephalographer will usually review the spike detections and time samples.

Guidelines to Clinical Interpretation

Clinical interpretation of EEG should take into account not only the EEG recording but also the clinical information that was provided. Unfortunately, this information can be quite limited, thus restricting the utility of the interpretation. As with all neurophysiologic interpretations, the EEG report represents a type of consultation. Therefore, the impression should not only be descriptive but also clinically useful.

An EEG report impression could read:

- "Abnormal study because of generalized asynchronous irregular theta and delta activity."

Such an interpretation may not be useful to the referring clinician.

The impression should include a summary of the key findings as well as a clinical interpretation. These could be divided into two paragraphs, as below

- *EEG Diagnosis*: "Abnormal study because of generalized asynchronous irregular theta and delta activity. No focal findings were seen."
- *Clinical Interpretation*: "This EEG consistent with a generalized encephalopathy, but is not specific as to etiology."

The impression is not a substitute for a description of the record. The body of the report would include a description of the record, including background, state changes, and presence and absence of normal and abnormal rhythms or transients. Any epileptiform and focal abnormalities, abnormal responses, or absence of response should be described. The clinical interpretation may need to be tailored to the question asked. For example, if the clinical question is "rule out status epilepticus," it would be helpful for the clinical interpretation to add "there was no seizure activity."

Epilepsy monitoring unit reports follow the same guidelines. In our center, the report includes, in addition to identifying information, the following:

- A preamble summarizing the background information and the reason for the study;
- A description of the baseline EEG (this is like a standard EEG with hyperventilation and photic stimulation, performed within the first day of admission);
- A daily description of clinical seizures and their electrographic correlate;
- A daily description of the interictal abnormalities;
- EEG diagnosis summarizing the key abnormalities, starting with ictal discharges (focusing on localization at onset), then interictal discharges, then non-epileptiform abnormalities;
- Clinical interpretation. In this section, the clinical seizure description is provided first, with a statement about the localizing and lateralizing value of the seizure signs, then a statement about how the semiology agrees (or not) with the EEG ictal onset and other EEG abnormalities, and then a summary synthesis of all the findings, to provide a seizure diagnosis, classification, lateralization, and localization, together with the degree of certainty of these determinations.

Activation Methods

Overview

Activation methods are routinely used for inducement of epileptiform activity in patients with suspected seizures. Activation methods include hyperventilation, photic stimulation, and sleep deprivation. Details of the methods of hyperventilation and photic stimulation were presented above.

Hyperventilation

Hyperventilation is used predominantly to activate the 3-per-second spike and wave discharge of absence epilepsy. In some patients, the discharges are only seen during hyperventilation.

The normal response to hyperventilation is diffuse slowing with appearance of theta range activity. The slowing is higher in children than in adults and patients with hypoglycemia.

Photic Stimulation

Photic stimulation is especially helpful for the identification of primary generalized epilepsies with motor symptoms.

Responses to photic stimulation can be normal, abnormal, or artifactual. These are:

- Normal:
- Visual evoked response;
- Driving response.
- Abnormal:
- Photoparoxysmal response.
- Artifact:
- Photoelectric artifact;
- Photomyoclonic response.

Examples of responses to photic stimulation are presented in Chapter 4 on Clinical EEG, and are summarized in brief here.

Visual Evoked Response (VER)

The visual evoked response or photic evoked response is the same potential that is recorded during flash evoked potentials. This has a major positive component from the occipital leads, O1 and O2; it occurs approximately 100 msec after each stimulus. It is seen mainly at flash frequencies of 5/sec and less.

Driving Response

The driving response appears with faster flash frequencies, 7/sec and up. Unlike the evoked response, it is time-locked to the stimulus.

Photomyoclonic Response

The photomyoclonic response is EMG activity in the frontal scalp muscles induced by the flash. Only susceptible individuals will show this rhythmic activity. There is about 50–60 msec between the flash and the EMG activity.

Photoparoxysmal Response

The photoparoxysmal or photoconvulsive response is uncommon but is a fairly good marker for seizure tendency. The discharge typically starts later than the onset of the flash and does not terminate when the flash train does. Differentiation from non-paroxysmal activity is discussed in Chapter 4.

Photoelectric Artifact

The photoelectric artifact is produced by light from the photic strobe interacting with the electrode-gel complex. This is a chemical charge movement and not physiologic.

It is non-cerebral and is not EMG. The potential is generated by the electrode-gel complex.

Sleep Deprivation

Sleep deprivation increases the possibility of seeing epileptiform activity, and therefore is used for patients in whom routine EEG has not been able to identify interictal epileptiform activity. Although sleep is sought in most EEGs performed for suspected epilepsy, sleep deprivation is still considered a physiologic activation method.

Video EEG and Long-term EEG Monitoring

EEG monitoring includes video-EEG and prolonged EEG recordings even without video recording, but this monitoring is most effective when video is included. These techniques were once the arena only of academic institutions, but with improvements in technology, video EEG is available in most hospitals and in some office practices.

Brief video EEG is typically performed in the hospital or office for one or more hours, usually lasting up to a working day. The video is captured along with the EEG. We prefer to use two monitors, with video on one and EEG on the other, but this is not universally available. Modern EEG software generally supports dual monitor display.

Long-term video EEG is typically performed in the epilepsy monitoring unit (EMU). However, long-term EEG can also be performed in some sleep labs and is often performed in hospital rooms, or in the ICU.

Long-term EEG recording without video is often performed in office and hospitals that do not have video recording capability. While these studies are often helpful, video should be used if available, and the cost of acquisition of video capability is quite reasonable.

Ambulatory EEG can be a good option for offices that do not have easy access to long-term inpatient monitoring or for patients who do not have seizures in the EMU but only in their normal outpatient environment. We have used ambulatory EEG for many years, but the lack of good clinical-EEG correlation afforded by inpatient study makes the latter preferable. There are home video-EEG devices, but we have no experience with these systems.

Clinical Indications for Video EEG

Video EEG is used for direct correlation of clinical events with EEG. This is especially of use when patients are having events that might be seizures. It is also helpful for patients with abnormal EEG in whom the electroencephalographer needs to visualize the clinical appearance (i.e., does the patient have a clinical correlate to a finding on EEG?).

Prolonged video EEG monitoring was developed for more direct evaluation of seizures. The 20-minute “routine” EEG is only an indirect assessment in patients with seizures and spells of an unknown nature. Aside from select syndromes, such as childhood absence epilepsy and benign epilepsy with centrotemporal spikes, the interictal EEG is often normal in patients with epilepsy.

If the diagnosis of epilepsy was assured clinically, treatment could proceed without the need for EEG evidence, but the EEG is still of assistance in medication selection. However, when seizures do not respond to initial therapy, doubts arise regarding the certainty of the epilepsy diagnosis or the certainty of the epilepsy classification. The most solid clinical diagnosis requires the ability to witness and analyze a typical seizure and its EEG correlate. The technology of video EEG allows the capturing of events and provides the ability to replay seizures an unlimited number of times for detailed analysis of the clinical signs and the corresponding EEG changes.

The main indications for video EEG monitoring are:

- *Diagnosis of atypical seizures or spells of unknown nature*. The need for video EEG could arise because events are atypical for seizures, because there has been absence of evidence for epilepsy by history and by tests, because there has been no response to antiepileptic drug (AED) therapy, or because a patient with known epilepsy started having new “different” spells.
- *Accurate classification of seizures for optimal choice of medical therapy*. This situation applies to individuals with documented epilepsy in whom there may be incomplete or contradictory clinical and EEG data for classification purposes. An example of this would include an adolescent with staring spells and an EEG that shows both focal and generalized discharges. The seizures could represent generalized absence seizures, in which case the most appropriate therapy could be ethosuximide or complex partial seizures, in which case ethosuximide would be ineffective and a medication more appropriate for partial seizures could be best suited.
- *Localization of the epileptogenic focus for possible surgical resection*. There is evidence to suggest that after failure of two antiepileptic drugs, the chances of seizure freedom with another agent decreases markedly. Patients refractory to medical therapy should be investigated for the presence of a surgically remediable epileptic syndrome.

Additional indications for video EEG monitoring include:

- *Quantification of seizures*. Although this tends to be a research application, it could be clinically useful in counting frequent seizures that can be easily counted on EEG, for example generalized absence seizures.
- *Quantification of response to treatment*. This is also frequently a research application, but has clinical application for checking the efficacy of therapy of absence seizures in childhood absence epilepsy. In this syndrome, seizures are frequent, and the response can be quantified with a 24-hour monitoring study.

- *Studying seizure precipitants* described in the history.
- *Reflex epilepsy*: video EEG monitoring can easily record seizures if the reflex precipitant can be reproduced.
- *Self-induction*: some patients have resistant seizures because of auto-induction. Video EEG monitoring can document the occurrence of auto-induction in this situation.
- *Situational factors*: when situational factors are reported to precipitate seizures, they may potentially be reproduced in the setting of the epilepsy monitoring unit.
- *Documentation of ictal and interictal discharges during circadian rhythms*. This is frequently a research application.
- *Clinical correlate of EEG discharge*. Some patients have EEG discharges that could be ictal in nature. The presence or absence of clinical changes may be necessary for counseling regarding driving or other restrictions. Simultaneous video with the EEG allows testing and demonstration of changes in responsiveness or cognitive functions in conjunction with the EEG discharge.
- *Transitory cognitive impairment*. This is predominantly a research application. Very sensitive testing has allowed the demonstration of subtle dysfunction in association with interictal epileptiform discharges.
- *Finding interictal evidence for epilepsy*. This application does not necessarily require the video component.

EEG Monitoring Choices

Possible choices for video EEG monitoring include:

- Inpatient long-term video EEG monitoring;
- Inpatient short-term video-EEG monitoring;
- Ambulatory EEG monitoring.

Inpatient long-term video EEG is most appropriate for patients who are being evaluated for the possibility of epilepsy surgery. This is a definitive epilepsy diagnostic procedure for most patients with refractory epilepsy. It is seldom needed for patients with primary generalized epilepsy. The sensitivity of inpatient monitoring is increased by longer term recordings—up to several days—and by withdrawal of AEDs. Withdrawal of especially levetiracetam and valproate may reveal discharges that may not be seen otherwise.

Short-term video EEG is most appropriate for patients with episodes that are frequent enough to have a reasonable expectation of being experienced during a recording of 8 hours or less. These are usually patients admitted for spells of uncertain etiology.

Ambulatory EEG is most appropriate for patients with episodes that may be induced by events in the patient's usual daily life. While some equipment does allow for a video component of the recording when the patient is in bed or otherwise stationary, most ambulatory EEG is electrocerebral-only. This means that the detailed character of the clinical event cannot be determined from the recording. Also, very subtle events can easily be missed, especially since much sharp activity can be presumed to be artifact without a clinical correlate.

Methods

Inpatient Long-term EEG Monitoring

This is performed in a fixed epilepsy monitoring unit. In this setting, the most up-to-date equipment uses cameras fixed in the patient rooms. Two cameras with different angles and zoom settings are possible but not mandatory. The electrodes attached to the patient's head are connected to a head box. Signals are amplified and transmitted through a cable to a computer that records the digitized EEG signal. The video signal is similarly digitized and synchronized.

Most epilepsy monitoring units currently use seizure and spike detection paradigms. These are extremely helpful for identifying seizures that patients are not aware of, but they have a very high false-positive detection rate so that every detection has to be reviewed to determine its validity.

Patients are typically admitted for several days. If they have been on anti-epileptic drugs, these drugs are reduced or discontinued in order to facilitate the recording of seizures. Some medications have to be withdrawn carefully, as they can be associated with particularly severe withdrawal seizures. This in particular has been demonstrated for carbamazepine. Identification of seizures can be performed in several ways.

Most video EEG units include:

- An event marker button that the patient or patient's family can push in the event of a seizure;
- Automatic seizure detection program;
- Seizure log/diary kept by the patient/family/caretaker;
- Screening the EEG or video.

Some manufacturers offer density spectral array display that could identify periods in which changes are suspicious and warrant review for possible seizures. This can markedly facilitate the review of EEG for possible seizures.

Using a combination of all of the above, long-term video EEG monitoring in the EMU is successful in the vast majority of patients in recording epileptic seizures for analysis.

Repeated Admissions

Occasionally, admission has to be repeated. If a second admission fails to record seizures, the approach to video EEG monitoring may have to be modified. One of the factors that contributes to the failure of video EEG monitoring is the elimination of daily life stressors when the patients are admitted. These stressors may be necessary to precipitate seizures.

Some patients have cyclical seizure patterns and the video EEG monitoring session would have the highest yield if scheduled at the next expected cycle. This is most commonly encountered in women with catamenial epilepsy in whom seizures are most likely just before or during the menstrual period. In other women, seizures are also more likely around the time of ovulation. Even men may have cyclical seizure precipitation, and the video EEG monitoring could have a higher yield taking these into consideration.

Monitoring for Presurgical Localization

If video EEG monitoring is scheduled for the purpose of presurgical seizure localization, then recording of three to six seizures is usually required. In the presence of conflicting data, a larger number of seizures may be needed to resolve the conflict and to increase certainty.

Some patients have independent left and right temporal seizure onsets, and these patients may still be candidates for surgery if more than 80% of seizures arise in one focus, or if only clinically insignificant seizures arise on one side and all clinically significant seizures arise on the other. In these more complicated cases, a larger number of seizures may be needed for accurate classification.

In some patients with independent interictal epileptiform discharges arising on both sides, a particular cluster of seizures may come from one of the two foci. In these patients, seizures cannot be recorded solely from a single cluster. Repeat monitoring at a different point in time may be advisable to record a separate cluster of seizures.

Monitoring for Differentiation of Epileptic from Non-epileptic Spells

If the purpose of monitoring is to determine whether a seizure is epileptic or non-epileptic, the recording of a highly typical non-epileptic seizure could be sufficient for the purposes of monitoring. However, there are potential pitfalls, and one should be extremely careful in the analysis of data. For many patients, recording additional seizures is advisable and continuing to record until anti-epileptic drugs have been cleared would provide further assurance. Some patients may have had epilepsy but new spells may be non-epileptic. The recording of a characteristic new spell that is non-epileptic does not necessarily eliminate the possibility of persistent controlled epilepsy.

Non-epileptic seizures are often provoked early with suggestion, whereas epileptic seizures will often appear at a latency, as anti-epileptic drugs are cleared. Some patients may erroneously identify an event as a typical seizure because they do not know what happens during a typical event. Not only can some patients with epilepsy be suggested to have a non-epileptic event, but others may spontaneously have an atypical psychogenic event in the charged environment. It is essential for a patient's family member to identify an event as typical. If typical events are recorded and are deemed psychogenic and nothing different happens after anti-epileptic drugs have been essentially completely cleared, then the possibility of pure psychogenic seizures is most likely. One can be most secure in this diagnosis when the onset of episodes is recent and it can be clearly confirmed that no events other than typical recorded ones have occurred in the past. The use of other suggestion techniques has been controversial. In particular, the element of deception that could be involved has been deemed unethical by many.

Also, caution should be exercised because some patients with epilepsy are suggestible and may be driven to have events that they don't normally have. Even patients with non-epileptic seizures may have typical attacks with suggestion. Hence, the verification with family members that recorded attacks are typical of historical ones is essential.

Monitoring for Classification of Seizure Type

If the purpose of the video EEG monitoring is to classify the seizure type, then recording of a single seizure may be sufficient if that recorded seizure has a clear focal onset and seizure semiology that agrees with the EEG localization. In other instances, however, one cannot be so certain with a single recorded seizure. In some patients, the seizure onset may appear generalized but the clinical seizure pattern may suggest a focal origin. In these instances, it may become necessary to record more than one event, in addition to interictal epileptiform activity.

Baseline EEG Recording

Ideally, every session of video EEG monitoring should be preceded by a baseline EEG. This baseline EEG provides the opportunity to record clean activity while the patient is relaxed and inactive. The posterior background rhythm can be recorded and its reactivity tested to eye opening and closure. Hyperventilation and photic stimulation should be a component of that baseline EEG if not contraindicated.

Provocation of Epileptic Seizures

Withdrawal of anti-epileptic drugs is the main method of precipitation of epileptic seizures used in the monitoring unit. However, other techniques can be added, particularly sleep deprivation. This is most effective for generalized epilepsy, particularly juvenile myoclonic epilepsy. In that condition, seizures sometimes occur only in the setting of sleep deprivation and usually after arousal from premature awakening. In partial epilepsy, sleep deprivation may be less effective. In patients whose seizures are predominately in sleep, particularly patients with frontal lobe epilepsy, sleep deprivation is useful only in as far as making seizures more likely with the next session of sleep. It is best in these instances to alternate sleep deprivation and full night's sleep. Using sleep deprivation on consecutive nights and days may not be justified or fruitful. If an ictal single-photon emission computed tomography (SPECT) is planned during the session of video EEG monitoring, sleep deprivation at night can be followed by allowing the patient to sleep during the daytime when the ictal SPECT injection is possible. This is most useful for patients whose seizures typically occur in sleep.

If a patient or family has noted a possible provoking experience, then this should be reproduced in the EMU as much as possible. For example, rare patients have seizures induced by reading, music, smells, or other experiences.

Withdrawal of AEDs is able to unmask some discharges that would be not seen with certain AEDs (e.g. levetiracetam, valproate, and benzodiazepines). In addition, withdrawal of AEDs can result in a greater tendency to have the seizure spread over the cortex, making it easier to see on scalp EEG.

Observation during the Study

Technician observation during the study should be an active encounter. There are events that might occur during a study which deserve some intervention by the technician. For example, if a seizure discharge is noted during a recording, the technician should give a command to the patient, or otherwise try to ascertain responsiveness. One command might be "Hold up two fingers" and note whether the patient makes a correct, incorrect, delayed, or no response.

Testing Patients during Events

In epilepsy monitoring units where patients are observed continuously and in any short-term video EEG monitoring where an EEG technologist is present, the testing of patients during events is of great clinical utility.

Testing is aimed at the following:

- Establish if the patient is unresponsive;
- Determine if there is impairment in specific areas;
- Determine if the patient has recollection for items given during the spell, or for events that occurred during the spell.

The authors suggest that the patient's ability to follow commands and to name items be tested at baseline. Should a suspicious ictal EEG activity appear or any behavioral changes occur that are suggestive of a seizure, then the patient should be given a command, the response to which can be assessed visually upon video review. For example, the patient could be asked to point to the ceiling, touch his/her nose, or clap his/her hands. The patient can then be given items to name and to remember.

One study used a sentence from the Boston Diagnostic Aphasic Battery, "I heard him speak over the radio last night," to assess reading abilities postictally (Privitera et al., 1991). Patients with left temporal seizures usually required more than one minute from the termination of the seizure to read the sentence correctly. Patients with right temporal lobe seizures were able to read the sentence within one minute from seizure termination.

When the patient has fully recovered, memory can be tested by asking for items given during the seizure as well as for events during a seizure. For example, it is not uncommon for patients with right temporal lobe seizures to produce spontaneous sentences (often with a twinge of fear) and respond almost normally to commands or other verbal stimuli. Once the seizure is over, it is quite common for these patients not to remember the conversation.

Testing during Hyperventilation

Testing is sometimes useful to identify whether a seizure has occurred or the EEG discharge was subclinical/asymptomatic. In patients with generalized absence seizures, it is recognized that even a single spike-and-wave discharge is usually associated with a neurological change when sufficiently sensitive testing is used. However, the degree of gross alteration of responsiveness and awareness varies tremendously between patients such that some patients have no gross detectable change. Testing patients' responsiveness during generalized spike-and-wave discharges should be routine when the EEG technologist is present during the baseline EEG or a session of short-term monitoring.

During hyperventilation, a common EEG response is generalized bisynchronous delta activity that is totally normal, particularly for younger children (Epstein et al., 1994; Lum et al., 2002). However, a rare pattern of absence seizures involve 3-Hz delta activity without coexistent spikes. Because of this pattern, it is also advisable to test patients who have a sustained generalized 3-Hz delta activity during hyperventilation, to determine if responsiveness is altered. A definite diagnosis of absence seizures is not possible without demonstrating a clinical alteration.

End of the Study

When Should the Study End?

The video EEG monitoring study ends once a sufficient number of seizures have been recorded and the patient has been stabilized. In patients who develop a cluster of seizures or who have generalized tonic-clonic seizures during the monitoring session, one day without seizures would be advisable before discharge. Certainly, the safety of discharge also depends on many individual factors, such as whether the patient lives alone and how far the patient lives from the medical center or from an emergency department. A patient who lives alone requires a greater evidence of stability prior to discharge.

Medications upon Discharge

The admission to the epilepsy monitoring unit presents an opportunity to make medication changes for many patients. For patients with documented epilepsy, the admission could be an opportunity to withdraw a medication such as carbamazepine that would be difficult to withdraw on outpatient basis. The inpatient setting allows a faster withdrawal and treatment of consequences with intravenous or p.o. medications on an as-needed basis.

For patients with non-epileptic psychogenic seizures and no evidence of epilepsy, it is most appropriate to discontinue anti-epileptic drugs prior to discharge. As a component of the treatment of patients with non-epileptic seizures, withdrawal of anti-epileptic drugs helps remove the ambiguity about the diagnosis so that effective treatment can be pursued, with psychotherapy or psychiatric medications as needed.

Short-term Video EEG Monitoring

This form of video EEG monitoring is performed for 2 to 8 hours on either outpatient or inpatient basis. This form of monitoring avoids the need for hospital admission. It is the preferred form of monitoring for children and adults who have very frequent attacks or for patients in whom attacks can be reliably precipitated. For example, a variety of reflex epilepsies can be diagnosed on outpatient video EEG. Examples could include photosensitive epilepsy, startle epilepsy, reading epilepsy, eating epilepsy, and musicogenic epilepsy.

If the short-term video monitoring session fails to record an attack despite the use of appropriate activation techniques, then prolonged inpatient monitoring could be performed. It is often impractical and inappropriate to make medication changes in short-term video monitoring sessions. An exception could be the individual who reports that missing a single dose of medication reliably brings on attacks, or the individual who has only very mild events that would not present a risk.

Ambulatory EEG Monitoring

Ambulatory EEG has the advantage of keeping the patient in an environment that includes the usual stressors. Most commonly, this technology is applied without the video component. In the absence of video, interpretation of ambulatory EEG presents many challenges. It is well-known that artifact can imitate any EEG abnormality, and without knowing the concomitant behavior one cannot exclude the possibility that movement or other patterns of muscle activity and behavior could be responsible. Similarly, EEG discharge can be misread as movement or other artifact without video or other observational correlate.

Ambulatory EEG alone would be most helpful in major attacks that involve loss of consciousness or complete loss of awareness. In these instances, the persistence of a normal EEG strongly suggests a non-epileptic etiology. Ambulatory EEG becomes less appropriate for subtle events, in particular events that do not involve alteration of awareness.

The use of video in conjunction with ambulatory EEG is provided by some manufacturers. This concomitant video use is possible when the patient is stationary, for example working at a desk, sitting on a sofa, or sleeping.

Special Electrodes

Clearly, diagnostic video EEG studies may not need special electrode use. However, additional electrodes besides the 10-20 system may be very useful for localization purposes. Electrodes can be added from the 10-10 system as needed, depending on the specific suspected localization. Methodology for special electrodes was discussed previously, but the utility of some of these is briefly reviewed here.

- *Nasopharyngeal electrodes*: Mostly to record from the medial-basal temporal cortex.
- *Sphenoidal electrodes*: Especially helpful for temporal lobe foci that cannot be identified otherwise. Sometimes, sphenoidal are the only extracranial electrodes to show the discharge.
- *Supraorbital electrodes*: For suspected orbitofrontal seizure origin.
- *Foramen ovale electrodes*: For discharges from the medial-basal temporal lobe.

EEG Review by Technologist

Review by the technicians is performed daily on patients admitted for prolonged monitoring. The review includes evaluation of burst detections. Any potentially abnormal pages are reviewed for characterization. Density spectral array (DSA) is reviewed for change in spectral power, which may suggest a seizure (Figures **3-50**, **3-51**). Clinical seizures as documented by staff, patient, and/or family are reviewed in detail.

Figure 3-50:

Figure 3-51:

Technicians create the technical noted based on this initial review. This is an aide to the reading physician, guiding where to look in a long recording for abnormal electrocerebral activity or clinical events.

The video is reviewed for every seizure starting approximately 30 seconds before the reported seizure onset. The first clinical change is noted. The analysis of the seizure should focus on early manifestations, particularly ones that have lateralizing or localizing value. While the video is reviewed, a cursor points out the exact timing of every clinical feature in relation to the EEG (see Figure **3-52**). The vertical line on the figure demonstrates the exact time on EEG corresponding to the video image.

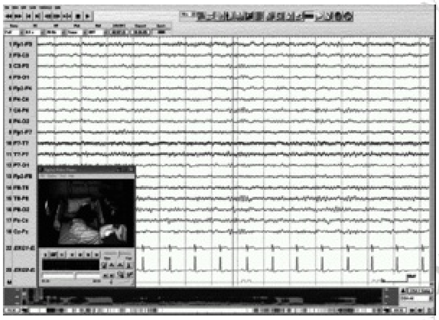

Figure 3-52:

Figure **3-53** provides an example of annotations entered on the EEG to describe clinical as well as EEG features during a seizure. These annotations can be exported to the EEG report with their corresponding times.

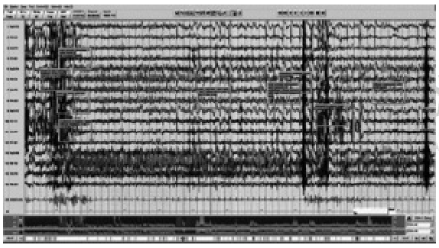

Figure 3-53:

Clinical annotations are entered at the cursor, making sure that the timing corresponds (see Figure **3-53**). The end of the clinical seizure is also annotated. In some cases, it is of value to review postictal manifestations, particularly the presence of aphasia. After annotating the clinical manifestations, the EEGer should review the corresponding EEG, focusing on the initial EEG changes. The EEG recording is annotated with description of EEG features/patterns according to the time of occurrence of each feature. Annotation should include features of known clinical value, for example 5 Hz or faster rhythmic activity in a temporal electrode within 30 seconds of seizure onset, which would favor a mesial temporal origin. Seizure termination should also be annotated. These annotations can be exported to the report with their timing.

Safety in the Epilepsy Monitoring Unit

Safety in the EMU is a major concern not only because the patients are on the clinicians' territory and under their personal care, but also because frequently patients are provoked to have seizures through activation procedures and withdrawal of AEDs. In addition, some potential risks, such as falls, are of particular sensitivity to health care institutions, so we must be sensitive to the risks without being so overprotective as to lower patient satisfaction or reduce the diagnostic sensitivity of the study.

Events can be separated into epileptic and non-epileptic events. They are considered individually.

Epileptic Serious Events

Severe seizures:

Seizures are usually not associated with serious injury, but they can be. After withdrawal of AEDs, seizures are not only more frequent but are more likely to be prolonged and more severe.

Status epilepticus (SE):

SE is more likely after withdrawal of AEDs, but is probably not increased by activation methods. Standard therapy for status epilepticus should be available with rapid access to clinicians who can activate the protocols. Vanderbilt University Hospital has a protocol for SE that is reproduced in Chapter 7. EMUs should have protocols for the management of severe seizures and SE.

Aspiration:

Aspiration is a common risk with seizures, especially generalized tonic-clonic seizures. Maintenance of adequate airway and suctioning as needed are warranted. However, if patients have partial seizures or other seizures for which aspiration risk is not high, then manipulating the patient during a seizure being recorded should be avoided. Of course, patient safety is always a higher priority than an EMU recording.

Falls during seizures:

Falls during seizures are uncommon, but significant head or other bodily injury can occur (Noe and Drazkowski, 2009). In addition, falls in the hospital setting are a particular concern for patients' safety. If the patient has significant ataxia or other issues that predispose to falls, fall-prevention protocols are available in most hospitals.

Postictal Psychosis

Postictal psychosis is uncommon but is occasionally seen and has been an occasional cause of postictal injury (Kanemoto et al., 2012). Patients with epilepsy have an increased risk of psychological difficulties even independent of the seizures themselves, but psychosis around the time of seizure is of particular concern. Medications such as olanzapine are used when needed, but the potential for exacerbation of seizures with some of the neuroleptics has to be considered.

Ictal Cardiac Asystole

Cardiac arrhythmias and asystole can occur anywhere in the hospital, including the epilepsy monitoring unit, but patients with epilepsy are more likely to have sudden cardiac death. Arrhythmia including asystole associated with a seizure—ictal cardiac asystole—is uncommon but needs to be considered and evaluated by cardiac rhythm recording along with other physiological monitoring. Incidence is far less than 1% of patients evaluated in the EMU (Marynissen et al., 2012). Ictal asystole can occur not only with generalized seizures but also with partial seizures (Agostini et al., 2012).

Sudden Unexplained Death in Epilepsy (SUDEP)

SUDEP is sudden death in patients with epilepsy, which is felt to be usually related to a seizure but not always—the patient may have sudden death without a clinical seizure. Cause is not entirely understood and may be multifactorial. Cardiac arrhythmia and apnea are two prominent possibilities, along with autonomic and other central causes (Moseley et al., 2012).

While SUDEP is not preventable, therapeutic treatment with AEDs is felt to reduce the risk (Surges and Sander, 2012).

Non-epileptic Serious Events

Cardiac Arrhythmias

Cardiac arrhythmias are more common in patients with epilepsy. Autonomic changes are common, but occasionally atrial fibrillation or atrial flutter can develop (Herskovitz and Schiller, 2012). This risk raises the possibility that if a patient with syncope is found to have atrial fibrillation, the neurologist should at least consider the possibility that the arrhythmia was related to seizure disorder.

Hypoglycemia

Hypoglycemia is an occasional risk in the epilepsy monitoring unit, especially if the patient is kept without eating for a time after a clinical seizure. Hypoglycemia can also trigger seizures and has even been reported to be a trigger of seizures otherwise felt to be epileptic (Monami et al., 2005).

Hypotension

Hypotension can occur during epilepsy monitoring as part of orthostasis and/or prolonged bed rest. In addition, hypotension can be an adverse effect of treatment for seizures; the more meds are needed, the greater the chance of requiring blood pressure support (Kowalski et al., 2012)

Psychiatric Disease

Psychiatric disorders are higher in prevalence in patients with epilepsy than the general population. Patients with epilepsy controlled have a much lower rate of psychiatric disorders than those with incomplete control (Kanemoto et al., 2012). In addition, postictal psychosis is seen, especially in patients with temporal lobe epilepsy (Sakakibara et al., 2012). Comprehensive psychiatric management of psychosis, depression, and even suicidal ideation needs to be addressed for patients identified as at risk.

Clinical Interpretation

Reviewing Studies

In reviewing video EEG studies, the interpreter places the greatest emphasis on ictal clinical events. There are clinical and EEG features to each of these events.

Clinical features to be assessed are:

- Time of occurrence;
- Activity the patient was engaged in;
- Apparent precipitation;
- Time of first clinical change and the nature of the first clinical change;

- Evolution of clinical activity and a description of activity at each phase and its evolution;
- Apparent end of the clinical event;
- Duration of the clinical seizure, and the nature of postictal behavior including interaction with examiners;
- Time of return to normal functioning should be recorded, if possible.

EEG features to be assessed are:

- State of the patient at the time the event started (for example, waking versus sleep).
- First change in the EEG, including attenuation or disappearance of previous interictal epileptiform activity and attenuation of previous background activity. If the attenuation is focal, this can be a useful localizing finding.
- First definite rhythmic activity and its localization, its evolution and pattern of spread, and the time of its termination.
- It may be noted when ictal activity ends in one hemisphere or in the whole brain except one region.
- Time of complete termination of the ictal discharge.
- Postictal EEG pattern (for example, generalized attenuation or lateralized or focal attenuation, or lateralized or focal irregular slow activity).

Filtering

The reviewer must look at the EEG unfiltered. Reviewing the ictal EEG in a filtered state first could result in misinterpretation of muscle and movement artifact as cerebral in origin, because they have lost some of their characteristic hallmarks as a result of the filtering. The pattern of muscle artifact during a seizure can be greatly helpful. For example, generalized tonic and generalized clonic motor activity both produce typical myogenic patterns on the EEG. Subtle focal clonic activity in the face can be recognized on EEG but not clinically, and chewing and swallowing artifacts can also be recognized on the EEG.

Montages

For purposes of localization and classification, seizures may need to be viewed in more than one montage. Using an initial bipolar montage, one can suspect the center of the field based on reversal of polarity or phase reversal. The seizure can then be viewed in a referential montage, choosing a reference that is least likely to be involved in the seizure activity. For example, an anterior-inferomesial temporal seizure origin of the ipsilateral ear is an inappropriate reference. The ear ipsilateral to the seizure origin is frequently involved in the ictal discharge. The average reference can be appropriate but may need to be manipulated to exclude the most clearly involved electrodes. Thoughtful consideration must be applied to select the montage that likely provides the highest fidelity.

Video EEG Diagnosis of Psychogenic Seizures

The simplest diagnosis of psychogenic seizures occurs in the absence of motor activity in patients who become unresponsive or who collapse and become unresponsive. In these patients, the presence of a completely normal EEG background while the patient is totally unresponsive would be diagnostic of a non-organic psychogenic activity.

A positive diagnosis of non-epileptic psychogenic seizures becomes harder in the presence of associated motor activity. In many instances, movement and muscle artifact can dominate the EEG, rendering its analysis impossible. In such instances, analysis of the video component becomes the predominant basis for diagnosis. That could be potentially misleading, as epileptic seizures can be very bizarre in their manifestations, with minimal associated EEG change when they arise from the mesial frontal or orbitofrontal region.

The video analysis of psychogenic seizures should also take into consideration that no single feature or even combination of features are totally specific. It is not uncommon for rhythmic movement to be associated with rhythmic motion artifact that could mislead into a diagnosis of seizure activity. Clues to the diagnosis could come from brief quiet periods that still include unresponsiveness or from the immediate postictal state when the patient is still unresponsive but quiet, allowing for a perfectly normal EEG to show through. When such periods are absent, the pattern of artifact can be helpful.

The rhythmic activity of epileptic seizures will usually evolve or at least wax and wane in its frequency, morphology, and amplitude. The rhythmic activity associated with non-epileptic seizures is either constant or includes irregularities that reflect on the EEG artifact. The occurrence of seizures immediately out of sleep is strong evidence against a psychogenic basis. Some patients with psychogenic seizures report that attacks occur out of sleep, but the EEG will usually demonstrate a waking background at onset.

Physician Interpretation and Reports

The video EEG report should start with identifying information, duration of study, a preamble that includes the reason for the study and background clinical information of relevance, medications, seizure medication changes during the study, electrodes used (for example 10-20 system, sphenoidal electrodes, T1/T2, etc.). Some centers produce a separate report for every day of recording. We prefer to have a unified report that includes a section for every day of recording, identified by dates and times. Typically the first day includes a baseline EEG, which is a 20-minute recording that cycles through standard montages (longitudinal bipolar average reference, ear reference, transverse bipolar) and includes hyperventilation and intermittent photic stimulation. For every day, the report should include a description of seizures, starting with clinical features by time of occurrence and then EEG features by time of occurrence, as well as a description of interictal EEG including waking and sleep patterns as well as epileptiform, slow wave, and amplitude abnormalities. After the last day of recording, an *EEG Diagnosis* paragraph summarizes the key EEG findings by number, starting with ictal discharges, then interictal epileptiform abnormalities, then slow and amplitude abnormalities, and posterior rhythm. The final part of the report is *Clinical Interpretation*, which is a synthesis of clinical and EEG data. We recommend starting with a summary description of the clinical features of the seizures, their lateralizing and localizing significance of the overall features, and how this is supported by ictal onset and interictal epileptiform and non-epileptiform abnormalities. There follows a summary statement. Below are examples of EEG diagnosis and clinical interpretations based on a variety of scenarios.

Scenario A: A patient with a psychogenic seizure and normal EEG

EEG Diagnosis:

- This EEG is normal in waking, drowsiness, and sleep.
- There is no EEG change in association with one typical spell, other than muscle and movement artifact.

Clinical Interpretation: This study recorded one of the patient's typical spells. The main features were (mention the most prominent features, stressing the ones that point to a psychogenic origin). There were no associated EEG changes other than muscle and movement artifact (if present). By both EEG and clinical criteria this spell was non-epileptic, most probably psychogenic in nature. In addition, due to the absence of interictal EEG abnormalities, this study fails to provide support for coexistent epilepsy.

Scenario B: Psychogenic seizure plus epileptiform abnormalities on the EEG

EEG Diagnosis:

- Frequent sharp waves recorded from the left temporal lobe.

- Intermittent irregular slow wave activity recorded from the left temporal lobe.
- There were no EEG changes (other than muscle and movement artifact) in association with one of the patient's typical spells.

Clinical Interpretation: This study recorded one of the patient's typical spells. Its main clinical features were....The EEG showed no change (other than muscle and movement artifact). By both clinical and EEG characteristics this spell was non-epileptic, and most probably psychogenic in origin.

On the other hand, the interictal EEG recorded left temporal sharp waves and suggested potential epileptogenicity in the left temporal region.

Scenario C: Predominantly subjective episodes or spells without definite altered awareness or responsiveness with a normal EEG.

Clinical Interpretation: This study recorded two episodes that were predominantly subjective. There were no associated EEG changes. This study does not support an epileptic nature for these attacks. However, since most simple partial seizures are not associated with scalp EEG changes, the possibility of simple partial seizures is not ruled out.

Scenario D: No spells and normal EEG

EEG Diagnosis: This is a normal 3-day video EEG study

Clinical Interpretation: No events were recorded. This normal study fails to provide support for the diagnosis of epilepsy but cannot rule it out, particularly in the absence of recorded attacks.

Scenario E: No spells but with interictal epileptiform discharges and slow activity

EEG Diagnosis: This 4-hour video EEG study is abnormal because of

- Frequent left anterior temporal epileptiform discharges;
- Left anterior temporal intermittent irregular delta activity

Clinical Interpretation: This study is most consistent with the interictal expression of partial epilepsy with a left anterior temporal potential epileptogenic zone.

Scenario F: Examples of recorded seizures with totally congruent data.

EEG Diagnosis: This 7-day video EEG study recorded:

- Two ictal discharges associated with clinical seizures. Both had a focal onset in the left inferomesial temporal region.
- Occasional left inferomesial temporal or left inferomesial temporal predominant sharp waves, which became extremely frequent during sleep.
- Occasional left temporal intermittent rhythmic delta activity (TIRDA).
- Intermittent left temporal irregular theta/delta activity.

Clinical Interpretation: This study recorded 2 complex partial seizures. The clinical onset was with cessation of normal activity, blank stare, chewing and swallowing movements, which favor a temporal involvement. Postictally after the first event, the patient was found to be aphasic for almost 2–3 minutes, which favors a left temporal localization. This localization was supported by the ictal EEG onset and interictal epileptiform and slow activity that was left inferomesial temporal or inferomesial temporal predominant.

In summary, this study is diagnostic of partial epilepsy with confident localization of the epileptogenic zone to the left inferomesial temporal region with excellent convergence of clinical seizure pattern, ictal EEG, interictal epileptiform activity, and slow wave activity.

Scenario G: Example of fairly congruent data, less definitive

Example 1. Left lateral temporal

EEG Diagnosis: This 3-day video EEG monitoring is abnormal because of:

- At least 16 ictal discharges with associated clinical seizures. All ictal discharges started with theta activity in the left temporal region (at T7, T1>P7, F7).
- Bursts of left temporal rhythmic sharp activity in sleep (F7>T7>Fp1) lasting up to 10 seconds, with some evolution raising the possibility of subclinical ictal discharges.
- Very frequent left temporal epileptiform discharges (T7 or F7 predominance).
- Left temporal intermittent irregular slow activity.

Clinical Interpretation: This 3-day video EEG study recorded 16 of patient's typical complex partial seizures. Their main characteristics were sudden crying/moaning, appearing restless and scared, mild right facial twitching, head turn to the left, and bilateral limb automatisms. The early head turning to the left and right facial twitching at onset may favor a left lateral temporal localization. This localization is supported by the ictal onset and interictal epileptiform and slow activity.

In summary, this study is diagnostic of partial epilepsy with a probable left epileptogenic zone in the left lateral temporal region.

Example 2. Left frontal

EEG Diagnosis: This 3-day video EEG study is abnormal because of:

- Fifteen ictal discharges associated with clinical seizures, 6 of which secondary generalized. All 15 seizures started from the left frontal region (F3>Fp1,F7,C3); 10 of the seizures started with transitional sharp waves.
- Frequent high frequency beta bursts recorded from the same region as above.
- Interictal epileptiform discharges from the left frontal or frontotemporal region.
- Irregular delta activity recorded from the left frontal region.

Clinical Interpretation: This 4-day video EEG study recorded 15 complex partial seizures, 6 secondarily generalized. The seizures included early head turning to the left, hypermotor automatisms of the left extremities, while the right side was motionless or posturing, and, in transition to generalization, adversive head turning to the right, and asymmetrical tonic posturing (with figure of 4). The clinical features strongly favor a left lateralization. The initial hypermotor activity may suggest frontal lobe involvement. A left frontal localization was supported by the ictal EEG onset and by the interictal epileptiform and slow activity, which were consistently left frontal.

In summary, this study is diagnostic of partial epilepsy, with strong evidence of a left frontal epileptogenic zone.

What Your Technologist Needs to Know

This discussion is not intended to be a comprehensive technical manual but rather a guideline as to what the EEG reader expects.

Training and Expertise

There is a national shortage of qualified EEG technologists and quite few training programs. Even the programs that do exist produce small numbers of technologists. Therefore, many EEGs are performed by technicians who are at various stages of training and experience, from novices to those eligible for ABRET registry to those who are registered to those who are qualified and experienced educators.

EEG labs should be supervised by a registered EEG technologist, or at the very least an individual who is eligible for ABRET certification. New technicians who have not gone through teaching programs should be supervised by a certified or eligible technologist.

Two organizations are integrally involved in advocating quality training of technologists. The American Society of Electroneurodiagnostic Technologists (ASET) is involved in education of technologists. The American Board of Registration of Electroencephalographic and Evoked Potential Technologists (ABRET) has a comprehensive examination that demonstrates competency in EEG, and also has published pathways for achieving eligibility for the examination. There are multiple pathways to certification and these may be in flux. ABRET documentation should be consulted for current information. The expectation is that technicians will proceed through one of these pathways to become successfully registered. A significant pay differential between registered and non-registered technicians can be an incentive to complete the programs and take the exams.

Separately from the technicians, we are increasingly depending on nurses in the critical care units to be able to perform clinically important interpretation of bedside EEG monitoring. ASET has resources for information through meetings and publications, and more will be expected.

As a separate issue from training, we expect that the technicians will be skilled in more than merely applying the electrodes and piloting the machinery. The technicians must know enough about EEG interpretation that they can identify common abnormalities, especially if the interpretation would dictate a change in the performance of the test or necessitate contact with a physician. Examples may include end-of-chain localization where alternative montage should be used, frequent seizure discharges, cardiac arrhythmia, or sleep apnea.

Infection Considerations

Infections are a constant concern for office and hospital EEG, but are of particular concern in patients in the ICU. Universal precautions are followed everywhere, and a major effort in hospitals is to ensure that proper hand hygiene, gowning, masks, and gloves are used when appropriate.

EEG electrodes are not invasive, but the skin prep process makes them potentially contaminated by abraded skin or serum. Cleaning with disinfectant is routine, soaking often until the next study. EEG electrodes and their leads can become further contaminated by secretions, especially with prolonged recording. Depending on the type and level of contamination, cleaning may have to extend to wiping down the head box and possibly other machinery with disinfectant. EEG electrodes used on patients with suspected Creutzfeldt-Jakob disease (CJD), AIDS, hepatitis, and some other infections may warrant additional antimicrobial treatment.

Red Flags

EEG technicians should be expected to not only place electrodes and run machinery, they should be expected to identify red flags during EEG performance. Some of these are potentially life threatening, while others should prompt the technician to alter the test procedures. Some examples follow:

Cardiac arrhythmia: Bradycardia or asystole or other arrhythmia may produce symptoms that can be confused with seizure. Therefore, the technician should be attuned to development of any cardiac irregularity.

Sleep apnea: Obstructive sleep apnea (OSA) is particularly common in our region (Tennessee), so it is not uncommon for sleep apnea to be suspected on the basis of the sleep phase of a routine or long-term EEG. If there are findings suggestive of OSA, then respiratory monitoring should be considered if available. Alternatively, referral for sleep lab testing may be appropriate. STOP-BANG scores for assessing risk of sleep apnea are now routinely performed in most hospitals, including ours.

Spike-like potentials: Some non-epileptic spike-like potentials can be easily confused with epileptiform activity. For some of these, such as 14 & 6 positive spikes, a change in montage to a contralateral ear reference (not an active electrode for those potentials) can clarify the interpretation of the recording.

Data Handling and Archive

Technicians are relied on to correctly annotate the records, and should give a summary of their findings, particularly drawing the attention of the reader to regions of particular interest. These findings are not for consumption as preliminary reports for clinicians, but can be of benefit to the reader.

Digital EEGs are usually stored on central servers and interpreted at workstations. Archiving the recordings is performed in accordance with regulations. Archiving is sometimes done by the technologists but sometimes by Information Systems (IS) or other support staff.

EEG machines and reading workstations are repositories and/or portals of personal medical information. Therefore, standard security measures should be followed, just as for a workstation or device with an electronic medical record or PACS system.

Oxford Medicine

Atlas of EEG, Seizure Semiology, and Management

Karl E. Misulis

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Clinical EEG

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Terminology and Definitions

Interpretation of clinical EEG begins with identification of the clinical state and events, and then identifying the EEG correlates to those states and events. For most patients, diagnosis can be accomplished by a routine EEG, but for some with uncommon events which need to be captured, prolonged recording is needed. Table 4-1 describes some common clinical states and events, and Table 4-2 describes some common EEG events. These and additional entities are subsequently discussed in the text.

Table 4-1 Clinical Events

Term	***Definition***
Epileptic seizure	Episodes of change in neurologic behavior due to abnormal neuronal activity in the brain
Psychogenic non-epileptic seizure	Episodic neurologic events that can resemble epileptic seizures but which are due to psychological issues rather than due to a change in neuronal activity in the brain.
Non-epileptic event	Episode of neurologic abnormality which can resemble epileptic seizure but is not primarily due to epileptic discharge. E.g. clonic syncope.

Table 4-2 EEG Events

Term	***Definition***
Spike	Sharp transient with a duration of 25–70 msec.
Sharp waive	Sharp transient with a duration of 70–200 msec.
Slow wave	Individual waves in the theta (4–13 Hz) or delta (< 4 Hz) range.
Sharply-contoured slow wave	Sharp transient with a duration > 200 msec.
Epileptiform discharge	Episodic waves or complexes that stand out from the background and suggest predisposition to epilepsy.
Spike-wave complex	Spike followed by a slow wave.
Posterior dominant rhythm	A rhythm from the occipital region that is composed of one fairly narrow band of dominant frequency. Waves of other frequencies may be superimposed on this posterior rhythm

Normal EEG

Overview

Clinical EEG is performed in the office or hospital setting, and is performed prior to long-term video EEG monitoring. The recordings are of only a small epoch, 20 minutes or so, therefore, it is very possible to miss epileptiform abnormalities on a recording of this duration. Encephalopathy is more difficult to miss, unless the entirety of the recording was made in the drowsy or sleeping state.

Normal EEG will be discussed first, followed by a discussion of artifacts and electrocerebral abnormalities.

EEG can be abnormal in two ways. First, there are some potentials that can be definitively abnormal. Second, some potentials are abnormal only in the context of baseline EEG activity and patient characteristics and state.

Non-epileptiform activity includes focal and generalized slowing, and other abnormalities of background activity. Interictal abnormalities include isolated spikes and sharp waves which also can be focal or generalized. Ictal activity is associated with clinical seizure activity and is usually repetitive spikes, again focal or generalized, although focal slowing or suppression or focal rhythmic activity of almost any frequency can be ictal activity.

The normal EEG is more difficult to specify than the normal EMG or Nerve Conduction Study. There are certainly specific rhythms that are expected at different ages and states of patients, but in addition, there are specific patterns that are independent of quantitative frequency analysis.

The normal EEG can be defined by:

- Frequency composition;
- Topographic organization of the activity—left/right, front/back, asymmetry, interhemispheric synchrony;
- State—including wake/sleep, tense/relaxed;
- Effect of activation methods on the EEG.

The normal EEG across ages is typically symmetric, though not synchronous across the hemispheres, and has a spatial and frequency distribution that is appropriate for the patient's age. Normal variants are often age-dependent, as are some normal EEG patterns.

Normal Adult EEG

Normal Waking Backgrounds

A variety of background rhythms will be seen in EEGs, many of which are distinctly abnormal. Sleep rhythms will be discussed later. The following patterns can be seen in the awake state and are distinctly normal.

Normal Posterior Dominant Rhythm

The occipital leads show rhythm in the alpha range. Frontal and central leads show faster activity. The posterior dominant alpha is present in relaxed wakefulness and attenuates with eye opening and disappears as the patient falls into drowsiness and sleep.

Low Voltage Fast

Some individuals have a very low-voltage posterior rhythm that it is nearly invisible, and a low-voltage fast background is seen. Similarly, patients who have difficulty relaxing may never get into the relaxed wakefulness that allows for the posterior dominant alpha rhythm. Absent of this posterior rhythm is not abnormal unless unilateral.

Sleep-wake Cycle

Waking State

Routine EEG (Figure **4-1**) usually begins with the patient awake with the eyes closed. The technician asks the patient to open and close the eyes to assess the posterior background rhythm and its reactivity. If activation methods are used, they are performed during the initial segment of the EEG. Finally, the patient is allowed to rest, progress into drowsiness, and possibly fall asleep. Evaluation of encephalopathy does not typically require a sleeping study, but evaluation for seizures is best if a sleep study is performed.

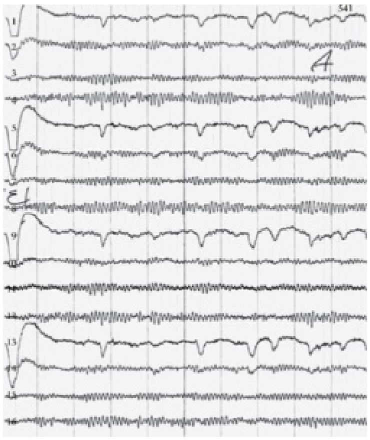

Figure 4-1:

Normal waking EEG using the longitudinal bipolar (LB) montage. Posterior-dominant alpha rhythm, with eye blinks anteriorly, is seen.

Adults with the eyes closed have a posterior dominant rhythm of about 10 Hz. The minimum allowable frequency is 8.5 Hz, and 11 Hz is the upper end of the range. Anterior cerebral EEG shows low-voltage fast activity. Eye movement artifact is superimposed. A frontal-predominant beta activity is seen when patients are sedated with benzodiazepines or barbiturates, but this is less prominent with chloral hydrate.

Quantitative EEG analysis shows a small amount of theta and delta during the awake state, but this is not prominent with visual analysis. Older patients have less prominent posterior dominant alpha activity. Also, tense patients may have little or no visible posterior dominant alpha-range activity. This should be commented on in the report, but not

interpreted as an abnormality in the absence of other findings.

Eye closure results in attenuation of the posterior dominant rhythm, as shown in Figure **4-2**.

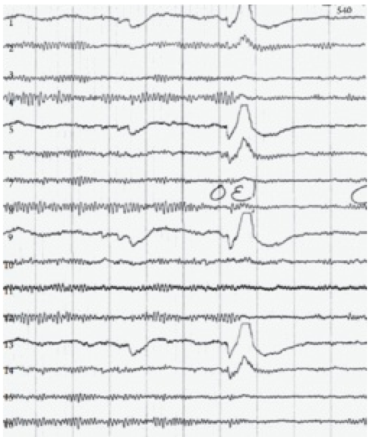

Figure 4-2:

There is attenuation of the posterior rhythm with eye opening. This is the same patient as in Figure **4-1**.

Drowsiness

Patients progress from waking to drowsiness, during which time there are several changes, including progressive reduction of muscle artifact, a slight reduction in the posterior rhythm frequency (usually not more than 1 Hz), anterior widening of the field of posterior dominant rhythm, and slow horizontal eye movements. This is sleep stage 1A. With progression to stage 1B, there is attenuation then loss of posterior dominant rhythm with the appearance of theta.

Vertex waves may be seen in stage 1B, but this is more of a characteristic of stage 2 sleep. Theta becomes more prominent. Differentiation of stage 1A from 1B is not important for routine EEG, but is important in sleep studies, as 3 consecutive epochs (1 epoch = 30 seconds) of stage IB is considered the onset of sleep.

Sleep

Sleep rhythms are described in Table 4-3. Composition of these features and background rhythms determines the sleep stages, as described in Table 4-4.

Table 4-3 Sleep Rhythms

Component	***Features***
Vertex wave	Negative potentials with a maximum at Cz.Prominent in stage 2 sleep and during arousal.
Sleep spindle	11–14 Hz waves of 1–2 sec duration.Maximum at C3 and C4.
K complex	Fusion of a vertex wave and a sleep spindle.prominent in stage 2 sleep and partial arousal.
Positive sharp transients of sleep (POSTS)	Positive potential with a maximum at O1 and O2.

Table 4-4 Sleep Stages

Stage	***Features***
Wake	Posterior dominant rhythm of 8.5–11 Hz.Desynchronized background.
Stage 1a (drowsiness)	Reduction in muscle artifact.Anterior widening of the field of the posterior dominant rhythm.Slow horizontal eye movements (SEM)
Stage 1b	Attenuation of the PDR.Appearance of theta activity.Vertex waves may appear.
Stage 2	Loss of the PDR.Sleep spindles.Vertex waves and K-complexes.
Stage 3	More delta activity (20–50% of EEG).Fewer vertex waves and spindles.Spindles become more anterior and slower in frequency.
Stage 4	Prominent delta (>50% of EEG).Vertex waves and spindles are few to none.
REM	Low-voltage fast background.Rapid eye movements.

Stage 2: Sleep is most easily recognized in stage 2. Stage 2 sleep is heralded by the presence of sleep spindles, more prominent vertex waves, and K-complexes, which are longer polyphasic vertex waves often associated with spindle activity. There is complete loss of the posterior dominant alpha rhythm. Since vertex waves may appear in drowsiness and sleep stage 1B, the main differentiating feature of stage 2 is the appearance of sleep spindles. Delta begins to appear at this stage.

Figure **4-3** shows an example of stage 2 sleep from the same patients as shown above for the waking records.

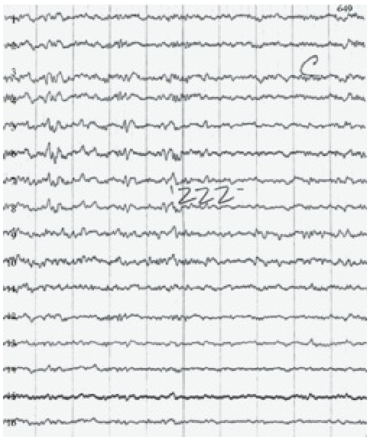

Figure 4-3:

The background is composed of a mixture of frequencies with sleep spindles and vertex waves. This is the same patient as in the previous two figures. Referential montage.

Stage 3: Stage 3 sleep is characterized by more delta and fewer faster frequencies. Delta comprises 20–50% of the record. Stage 3 sleep is not commonly seen in routine office EEG.

Stage 4: Delta activity predominates in stage 4 sleep, which now comprises more than 50% of the record. Vertex waves and sleep spindles are often absent. Stage 4 sleep is rarely seen on routine office EEG.

REM: Rapid eye movement sleep is characterized by a low-voltage fast background. Superficially, this pattern may resemble drowsiness, but is differentiated by rapid eye movements, hypotonia on submental EMG, and irregular respiratory rate.

Progression of sleep stages: Waking, drowsiness, and stage 2 sleep are commonly seen in routine office EEG. The progression is from waking to stage 1A to stage 1B to stage 2. With prolonged recordings, patients may progress to stage 3 then 4. The progression to stage 4 does not occur with each cycle. There are three to five cycles in a night's sleep. REM sleep occurs after at least one sleep cycle, and is of increased duration with later cycles.

Activation Methods

Activation methodology and response is discussed in Chapter 3 in the sections on *EEG Methodology* and *Routine EEG Review*. The responses to these activation are revisited here.

Photic Stimulation

Responses to photic stimulation can be normal, abnormal, or artifactual. Table 4-5 presents the photic stimulation responses that may be encountered.

Table 4-5 Photic Stimulation Responses

Type of response	***Response***	***Description***
Normal response	Visual evoked response	Occipital positive-predominant wave which peaks approximately 100 msec after the stimulus. Seen mainly at slow flash frequencies.
	Driving response	Occipital positive-predominant wave that is time-locked to the photic stimulus. Seen mainly at flash frequencies of 7/sec and greater.
Abnormal response	Photoparoxysmal response	Discharge evoked by flash usually in a band of frequencies. Associated with generalized epilepsies.
Artifact	Photoelectric artifact	Electrical activity generated at the electrode-gel interface by a flash stimulus. This is neither cerebral or muscle but rather electrochemical.
	Photomyoclonic response	Flash-induced electrical activity in the frontal muscles in response to a flash stimulus. Not a cerebral potential.

Not presented in Table 4-5 is induction of non-epileptic seizures by photic stimulation. Photic stimulation can induce both epileptic and non-epileptic seizures.

Visual Evoked Response

The visual evoked response is also sometimes termed the *photic evoked response* and is a positive-predominant wave seen from the occipital region approximately 100 msec after each flash (see Figure **4-4**). This is seen at slower flash frequencies, usually less than 5/sec. With increasing flash frequency, the VER disappears and the driving response appears, with the transition complete by flash frequencies of 10/s.

Figure 4-4:

Evoked response from the occipital region is seen approximately 100 msec after each flash.

The VER is the same potential that is recorded during visual evoked potential (VEP) testing, noting that during diagnostic VEP testing, pattern-reversal is the preferred mode of stimulus, and flash is used when pattern-reversal does not produce a response or cannot be done. The difference in appearance between VER and VEP is because of the method of data display and the absence of averaging.

The absence of a VER is not abnormal unless unilateral. Such asymmetry suggests abnormality in projections from one lateral geniculate to the cortex, or the calcarine cortex, itself.

Driving Response

The driving response appears as the flash frequency accelerates beyond 7/sec, and the next evoked potential starts before the last evoked potential has ended. It is created by the visual evoked responses merging into each other. The driving response is usually most prominent at the frequency of the posterior rhythm, or at multiples thereof (Figure **4-5**).

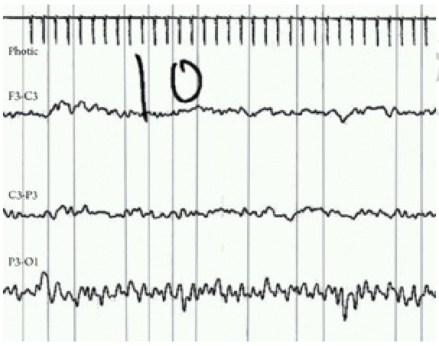

Figure 4-5:

Driving response is seen from the occipital region time-locked to the flashes.

Photic driving response is time-locked to the stimulus and appears at faster frequencies than the photic evoked response. The driving response is usually seen, but absence is not interpreted as an abnormality, unless unilateral or markedly asymmetric, in the absence of other abnormalities.

Photomyoclonic Response

The photomyoclonic response (Figure **4-6**) is not cerebral in origin, but rather is electrical activity in the frontal scalp muscles, which is induced by the flash stimulus in susceptible individuals. Repeated contraction of these muscles produces EMG activity that is time-locked to the stimulus, and recorded typically from the frontal leads.

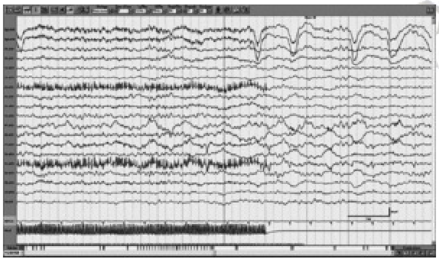

Figure 4-6:

Muscle activity with photic stimulation. The activity is more temporal than usual.

The main issue with the photomyoclonic response is in differentiation of this from photoparoxysmal response. Some general guidelines are discussed in Table 4-6.

Table 4-6 Differentiation of Photomyoclonic from Photoparoxysmal Responses		
Feature	***Photomyoclonic***	***Photoparoxysmal***
Spatial distribution	Anterior	Posterior or generalized
Termination	End of the stimulus	May stop before the end or outlast the stimulus.
Rise time of the spike	Fast (EMG) spike.	Slower, spike-and-wave complexes most common
Frequency	Same frequency as the flash	Frequency is independent of flash frequency, usually slower.

Photoparoxysmal Response

The photoparoxysmal response (Figure **4-7**) is a marker for seizure tendency, and most often noted with generalized epilepsies. Less commonly, photosensitivity is noted with partial epilepsy (occipital lobe epilepsy, and even less commonly temporal lobe epilepsy). While some patients will have already noticed that there is photic trigger of their seizures, this is not always the case. Some patients with photosensitivity have never had a spontaneous seizure.

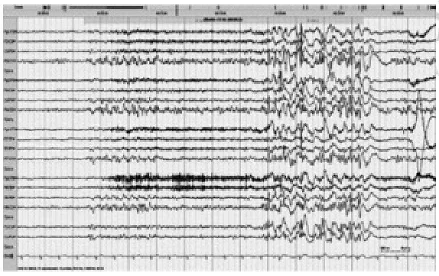

Figure 4-7:

Electrical discharge associated with photic stimulation.

The discharge is usually activated by a band of flash frequencies rather than by the entirety of the flash procedure. Identification of photoparoxysmal response is generally by the following criteria:

- Activated by a band of flash rates;
- Does not begin with the first flash in the train;
- Frequency is not time-locked to the stimulus;
- May outlast the photic stimulation train or stop before the end of the train.

The photoparoxysmal response is always interpreted as abnormal. It has been suggested that the best correlation with epilepsy occurs if the discharge outlasts the stimulus train, however this has not been consistently noted.

Photoelectric Artifact

The photoelectric artifact is non-cerebral and not EMG. The potential is generated by the electrode-gel complex. The artifact is often contaminating insecure leads with high impedance, so there is not equal representation across the forehead, and loss of common mode rejection.

Light produces changes in the electrode, which disturb subtle junction potentials between the electrode and gel. This potential is detected mostly in the frontal electrodes, which are directly illuminated and can be misinterpreted as a rhythmic spike potential with a frequency equal to the frequency of photic stimulation.

With solid electrode placement and fixation this artifact is minimized.It may be difficult to distinguish from the electroretinogram (ERG) activity that records potentials from the retina. The ERG is often seen in the frontopolar electrodes as well, at high gains, when there is a paucity of electrocerebral activity.

Hyperventilation

Hyperventilation is used predominantly to activate the 3-per-second spike and wave discharge of absence seizures. Patients with untreated childhood absence epilepsy will almost always have these discharges with hyperventilation. In some patients, the discharges are only seen during hyperventilation.

The normal response to hyperventilation is generalized slow activity, both synchronous and asynchronous. In adults, there is mostly appearance of theta range activity. The slow activity is more prominent in children than in adults and also more prominent and persistent in patients with hypoglycemia (Figure **4-8**).

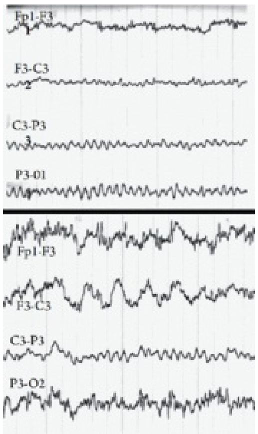

Figure 4-8:

Top: Normal EEG epoch. Bottom: Hyperventilation, with enhanced slow activity.

Hyperventilation is performed for 3 minutes on routine testing, and should be performed for 5 minutes if there is a strong suspicion of absence seizures. Hyperventilation is not performed in elderly patients and in those with significant vascular disease, since there may be resultant vasospasm and decreased cerebral perfusion.

Sleep Deprivation

Sleep deprivation increases the possibility of seeing epileptiform activity in some patients, and also increases the chance of obtaining sleep. Sleep deprivation increases the yield of epileptiform discharges beyond that expected from sleep alone, and therefore is considered a separate physiologic activation method. It is often used for patients in whom routine EEG has not been able to identify interictal epileptiform activity. Sleep deprivation may be a particularly potent activation method in patients with juvenile myoclonic epilepsy. In these patients, the highest yield is in recording most of the EEG after arousal from a brief nap following sleep deprivation.

Stimulus-Sensitive Epilepsies

Photic-induced epilepsy is not common but photic stimulation is presented during almost all EEGs, perhaps even during studies where this is not the clinical question. However, there are other stimulus-sensitive epilepsies that which should be considered (see Table 4-7).

Table 4-7 Stimulus Sensitive Epilepsies

Type	***Features***
Photic-induced epilepsy	Most common stimulus-sensitive epilepsy. Associated with generalized epilepsies especially and seen in people who have seizures even when the photic stimulation is not presented.
Musicogenic epilepsy	Uncommon and likely under-diagnosed epilepsy where seizures are triggered by listening to or performing music.
Reading epilepsy	Seizures precipitated by reading, likely rare yet under-diagnosed. Affected patients have seizures independent of reading also.
Other sensory-evoked seizures	Simple sensory stimuli such as tactile, auditory, and visual stimuli can evoke seizures in selected individuals. Most commonly seen with anoxic encephalopathy.

Musicogenic epilepsy is quite rare and likely under-diagnosed, as are stimulus-sensitive epilepsies in general (Maguire, 2012). The association with the music stimulus is often not obvious and when the diagnosis is made, there is usually a long history of neurologic evaluation without the stimulus sensitivity being identified. If a patient reports possible musicogenic epilepsy, the appropriate stimulus should be used if needed (Kasteleijn-Nolst Trenité, 2012).

Reading epilepsy is also rare but when suspected should be tested in the lab. These patients often have seizures when they are not reading and even sleeping, so the stimulus association is often not obvious. In this modern age of digital communication, cases of reading epilepsy induced by the omnipresent text messaging may make this diagnosis more evident (Watson et al., 2012).

Occasionally, patients with seizures may have spikes triggered by auditory or tactile stimulation as well as visual stimulation. This is particularly common in patients who have anoxic encephalopathy but can occur even if patients present with seizures not triggered by stimulus (Fernández-Torre et al., 2010). Another example of sensory-sensitive epilepsy is associated with tooth brushing.

Reactivity to External Stimuli

Reactivity to external stimuli during EEG is used not only to induce seizures but in this context refers to determining if the EEG exhibits reactivity separately from epileptiform discharge. During routine EEG, patients are often asked questions to determine level of consciousness and roughly determine cognitive function. In patients with hypoxic encephalopathy, lack of reactivity of the EEG can be a poor prognostic sign in the appropriate context—e.g., freedom from sedatives and time from hypothermia (Rossetti et al., 2010; Rossetti et al., 2012). Reactivity in a comatose patient is tested usually by presenting an expectedly painful stimulus, speaking to the patient even though a response is not expected, and making a loud unexpected sound, e.g., clap.

Reactivity in other conditions is also tested if a good waking record is not obtained, for the purpose of not only testing reactivity but also inducing a change of state of the sleep-wake cycle.

Placebo Infusion

Saline infusion during EEG has been used to both induce clinical events and to terminate documented non-epileptic events. This was discussed in Chapter 3 in greater detail, but is seldom used in clinical practice for ethical reasons. However, there is no doubt that this can be an effective technique and some clinicians use this as a technique of last resort (Wassmer et al., 2003).

Suggestions to Induce Seizures

Suggestions to induce seizures are commonly used, although some have objected to an air of deception that characterizes these suggestions. This was discussed in depth in Chapter 3. Technician suggestions are effective but are sometimes complicated to interpret; for example, patients without non-epileptic seizures might have one to suggestion even though they usually have epileptic events.

Hypnosis had been studied in adults and children in the potential to induce seizures. With a hypnotic suggestion to have a seizure during video EEG monitoring, both epileptic and non-epileptic events can be triggered, with non-epileptic events predominating (Khan et al., 2009). Regardless of whether the events are non-epileptic or epileptic, there is certainly diagnostic utility to having them revealed on study.

Effects of Aging

Aging results in some defined changes in EEG activity:

- Decreased voltage of the posterior dominant rhythm;
- Slight decrease in frequency of the posterior dominant rhythm;
- Increased theta and delta on spectral analysis;
- Increased beta activity;
- Decreased magnitude of the responses to photic stimulation;
- Decreased slowing in response to hyperventilation.

The PDR slows slightly with normal aging, but remains at least the minimum 8–8.5 Hz. Slowing to less than this is abnormal and consistent with encephalopathy.

The increased theta and delta with spectral analysis is difficult to see with visual inspection. A small amount of temporal theta is occasionally seen, and is discussed in a subsequent page.

Normal Pediatric EEG

Overview

The EEG in children is superficially similar to that in adults in that there is a posterior dominant rhythm that is attenuated and eventually replaced by slower activity in drowsiness and sleep. There are important differences, which are age and state dependent. Note that this book concentrates on adult EEG, which is the arena of the authors, so discussion of pediatric EEG is limited and basic.

Among these differences are:

- Frequency and appearance of the posterior dominant rhythm;
- Posterior slow waves of youth;
- Response to hyperventilation;
- Vertex waves appear higher voltage and sharper;
- Sleep spindles are often prolonged and higher voltage.

Neonatal EEG

Neonatal EEG is performed similarly to adult EEG, but the montages are somewhat different and there is more physiologic monitoring. Common physiologic monitoring usually includes:

- Respirations;
- Eye movements;
- Electrocardiogram (EKG);
- Electromyogram (EMG).

Respirations in adults are usually easily able to be differentiated from electrocerebral slow activity, but in neonates and young children, rapid respirations can be mistaken for pathologic slow activity.

Neonatal EEG is so different from adult that experience and competence in interpretation of adult studies does not assume competence in neonatal studies; this field requires specific training.

The following data need to be available for interpretation of neonatal studies:

- Age, including conceptional age, gestational age, postnatal age;
- Clinical question;
- Physiological state;
- Reactivity of the background.

Conceptional age (CA) is the sum of gestational age at the time of delivery plus postnatal age. This is important because some patterns continue to mature whether the maturation is intrauterine or post-delivery, in the case of premature infants.

Physiological state refers to observations regarding level of consciousness and the sleep-wake cycle (e.g., waking, sedated, or asleep). For sedated patients, it is helpful to know the agent used.

Reactivity of the background refers to response to tactile and verbal stimuli, and is important not only for neonates but for most routine and ICU EEGs.

Physiological State of Neonates

Normal sleep-wake patterns evident in children and adults are not seen early in premature infants. Normal term-infant EEG patterns are not well-developed until 38–40 weeks conceptional age. At term, there are two sleep stages defined—active sleep and quiet sleep. These are summarized in Table 4-8.

Table 4-8 Neonatal Sleep Stages	
Stage	***Description***
Active sleep (AS)	Small eye and body movements with irregular respirations.
Quiet sleep (QS)	Absence of eye movements and regular respirations. One pattern has continuous slow wave sleep with delta activity predominating with theta superimposed.
	Absence of eye movements and regular respirations but with a discontinuous, trace alternant, pattern with delta and some theta with superimposed bursts.

Active sleep (AS) is so termed because there are small eye and body movements. Respirations are irregular. This is equivalent to a REM sleep later in maturation. Theta predominates, with some delta and beta superimposed. The first AS epoch during sleep is higher amplitude than later epochs. Later epochs have not only lower amplitude but also more theta and less delta activity.

Quiet sleep (QS) is so termed because there are few to no eye and body movements. Respirations are regular. This is equivalent to non-REM sleep later in maturation. There are two patterns typically associated with QS. One is continuous slow activity predominantly in the delta range. The other is a discontinuous pattern, trace alternant, with epochs of alternating relative low-voltage activity punctuated by bursts of theta, which can be sharply contoured. This can occasionally look similar to a pathologic burst-suppression pattern, but the interburst activity with trace alternant is typically higher voltage and composed of a richer frequency of activities.

Normal Neonatal EEG

The normal neonatal EEG is so dependent on conceptional age that patterns need to be defined as typical of individual epochs of pre-term development. The EEG background typical of a term child is usually present by 38 weeks conceptional age.

EEG findings with different stages of development are presented in Table 4-9. To summarize, the youngest neonates commonly recorded (about 22 weeks) have a very discontinuous pattern, meaning that there are alternating periods of low-voltage activity punctuated by bursts of high voltage mixed-frequency activity, which commonly includes sharp waves. This can look similar to a burst-suppression pattern in an adult with severe encephalopathy or sedation.

Table 4-9 Neonatal EEG Patterns According to Conceptional Age	
Conceptional age	***EEG patterns***
22–29 weeks	Discontinuous pattern with long intervals of low voltage activity up to 2 min duration with brief high-voltage mixed-frequency bursts.
29–31 weeks	Discontinuous pattern with shorter interburst intervals.Delta brushes begin to appear.
32–34 weeks	Discontinuous pattern in quiet and active sleep.Multifocal sharp transients.
34–37 weeks	Discontinuous pattern in quiet sleep but with progressively shorter interburst intervals and increase in activity during the low voltage periods. Active sleep (REM) is almost continuous. Fewer multifocal sharp transients; more frontal sharp transients.
38–40 weeks	Trace alternant pattern in non-REM sleep with approximately equal bursts-interbursts. May be a continuous slow wave pattern. Fewer frontal sharp transients. No delta brushes.

With maturation, the periods of low voltage activity become shorter and have greater activity during this time. Therefore the bursts become more frequent and the difference between the bursts and interburst epochs are much less pronounced as the child approaches 38 weeks conceptional age—the discontinuity is quite modest at that point. As the child approaches 38–40 weeks conceptional age, sleep-wake cycles become more obvious.

22–29 Weeks Conceptional Age

EEG between 22 and 29 weeks CA consists of a discontinuous, mainly low-voltage mixed frequency activity with interspersed bursts of theta and faster frequencies (see Figure **4-9**). The interburst intervals can be more than 1 minute, especially in very premature infants, although shorter intervals are typical. The bursts exhibit poor inter-hemispheric synchrony in very young prematures, but later in this age group there is better synchrony. The discontinuous pattern is termed *trace discontinu* (TD).

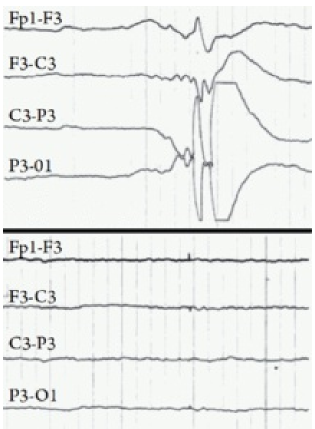

Figure 4-9:

Low voltage activity with infrequent bursts.

The sharp contours of these bursts, along with the quite low voltage of the interburst epochs, can cause the appearance to resemble pathological burst-suppression. This is differentiated chiefly by knowledge of age of the patient and clinical condition.

29–31 Weeks Conceptional Age

The discontinuous pattern persists, but there are changes, with the interburst intervals becoming shorter. The interburst intervals also are of higher amplitude still, with a mixed-frequency background.

The sleep stages are now present with the TD pattern seen in quiet sleep.

Delta brushes are typical of this conceptional age and are seen in active sleep. They have the appearance of a delta wave with superimposed fast activity in the alpha or beta range. They can resemble sleep spindles, but delta brushes are most prominent in the central and occipital regions, whereas the later occurring sleep spindles have a frontal predominance. Spindles are not seen at this age, and waves with spindle appearance could be epileptiform activity.

32–34 Weeks Conceptional Age

Both active and quiet sleep remain discontinuous, but the interburst intervals are of progressively higher amplitude and much shorter.

Delta brushes are seen, with the fast-component even faster in this conceptional age range. Delta activity is more prominent from the occipital regions.

Multifocal sharp transients are seen both in the waking and sleep states. This can easily be mistaken for pathological sharp waves, but the multifocal nature and the lack of repetitive discharge argues against epileptiform activity.

34–37 Weeks Conceptional Age

Active sleep is now virtually continuous, with irregular delta activity most prominent posteriorly and theta and faster frequencies anteriorly.

Quiet sleep shows a discontinuous pattern, but with shorter interburst intervals and higher voltage activity during the interburst intervals. Burst- interburst rations are 1:2 to 1:3.

EMG activity is a reliable indicator of state beginning at this age range, whereas it was not in younger prematures; low amplitude EMG is seen in REM sleep. Multifocal sharp transients disappear and are replaced with frontal sharp transients that are of higher amplitude.

Reactivity of the EEG is more prominent than in younger ages, with attenuation of the background with stimulation, and often a change of state.

38–40 Weeks Conceptional Age

These are considered term infants, and the EEG pattern is considered normal term EEG (Figure **4-10**).

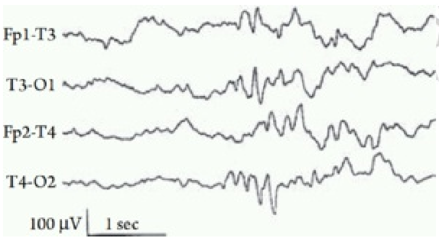

Figure 4-10:

Term infant shows a discontinuous pattern, less prominent than in the previous recording.

Non-REM sleep continues to show evolution of the discontinuous pattern, with less differentiation of the burst from interburst appearance. The burst-interburst ratio is now 1:1, and represents a mature trace alternant pattern. REM sleep shows a mixed pattern of alpha, theta, and delta with frequent eye movements and irregular respirations.

Frontal sharp transients are less prominent than in the younger age range, and abate totally after about 2 months post-term. Delta brushes are absent in this age range.

Maturation of the Posterior Dominant Rhythm

The normal waking background of the child depends on age. The posterior dominant rhythm is approximately 4 Hz in the infant and becomes faster throughout childhood, reaching 8 Hz by age 3, and the average adult frequency of 10 Hz by 10 years of age. Figure **4-11** shows the maturation of the posterior dominant rhythm. The amplitude tends to be higher than in adults, in the range of 50–100 µV.

Figure 4-11:

Change in the frequency of the posterior dominant rhythm with age.

Posterior Slow Waves of Youth

There are slow waves superimposed on and intermixed with the normal posterior waking background, referred to as *slow waves of youth*. These could potentially be confused with abnormal slow potentials indicating encephalopathy, especially in the young child with a posterior rhythm in the theta range. Posterior slow waves may have an episodic occurrence or may be seen sequentially. They are usually notched, suggesting that several alpha waves have merged to form them. They are not usually confused with epileptiform activity, although the sequence of an alpha wave followed by a slow wave occasionally suggests a sharp and slow wave complex.

In addition to posterior slow waves, there is more theta anteriorly in young children than in adults, and this, also, should not be interpreted as abnormal.

Neurophysiologists who are not accustomed to interpretation of children's EEGs often misinterpret normal slow activity as pathological slow activity, indicative of encephalopathy. Therefore, consideration must be made to age as well as the state of the patient (Figure **4-12**).

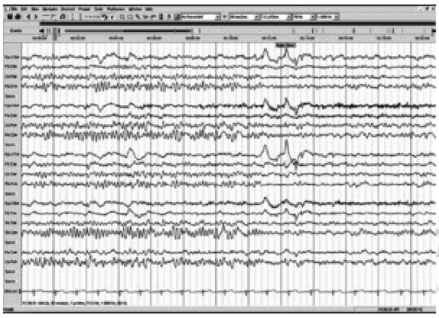

Figure 4-12:

On eye opening the slow waves of youth are blocked.

Posterior slow waves of youth are augmented by hyperventilation, as shown in Figure **4-13**. This is from the same patients as Figure **4-12**.

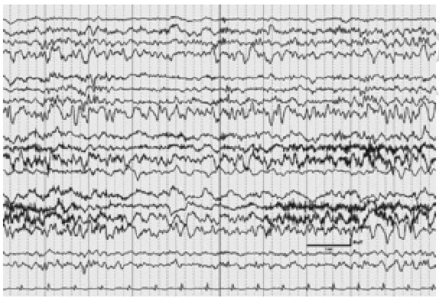

Figure 4-13:

Posterior slow waves of youth are considered normal. They are differentiated from pathologic slow waves by the following features:

- Otherwise normal background;
- Appearance in wake and light sleep but disappear later in sleep;
- Reactivity to eye opening—attenuated.

They become less evident with growth, and are not seen after 30 years of age.

Hyperventilation

Hyperventilation produces a greater reactive slowing in children than adults. In young children, the magnitude and synchronicity of the slowing can be mistaken for seizure activity (see Figure **4-14**). This is particularly true if there is a notched appearance to the rhythm, a common occurrence when the slow activity is superimposed on faster underlying rhythms.

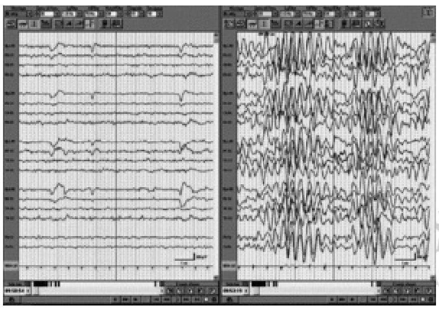

Figure 4-14:

Left side of the figure is before hyperventilation. Right side is with hyperventilation.

Drowsiness

One pattern of drowsiness seen in early childhood is that of generalized bisynchronous high voltage slow waves, often appearing abruptly. This pattern referred to a hypnagogic hypersynchrony. It becomes less frequent with advancing age, and is no longer seen by adolescence.

Sleep Patterns

Sleep should be obtained when the clinical question is seizures, since interictal discharges (and sometimes ictal discharges) are more common in sleep. For some patients, abnormal electrical activity is only seen in sleep. There is effectively no difference between sedated sleep and natural sleep. Chloral hydrate a commonly used sedative since it has a wide safety margin and this agent does not produce the prominent drug-induced beta activity that is typical of benzodiazepines and barbiturates. However, this is considered conscious sedation and requires monitoring of vital signs.

The sleep records of children and adults are more alike than the waking records. However, there are maturational changes in children. In addition, sleep activity of children can be particularly sharp and high in voltage.

Vertex Waves

Vertex waves (Figure **4-15**) are not present at birth, but begin to appear at about 5 months of age. By 2 years of age they are prominent in stage 2 sleep, sharp in configuration, and high amplitude. They can be so prominent as to be confused with epileptiform activity.

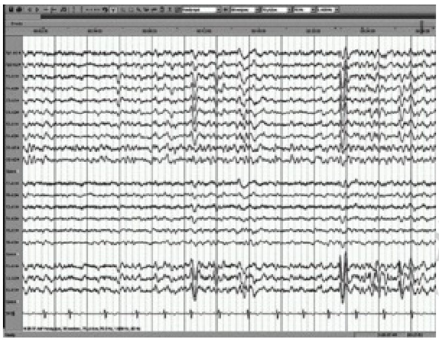

Figure 4-15:

While there is room for a lot of experience and judgment in differentiation of juvenile vertex activity from epileptiform activity, some general features of vertex waves are:

- Prominence during sleep without any signs of abnormal vertex activity during the awake state;
- Disappearance of the activity during deeper stages of sleep;
- Association of the activity with spindles;
- K-complexes that have a vertex component similar to the waves in question.

Regarding these guidelines, prominence in sleep without a waking correlate is different from augmentation during sleep. Occasionally, interictal or ictal activity will appear during sleep when there is no sign during the awake state. However, total absence during the awake state with prominence during light sleep is not impossible but is unexpected.

Disappearance during deeper sleep cannot be relied on in most routine office studies, because sleep beyond stage 2 is rarely obtained. Video-monitoring for longer time would be required to capture all sleep stages.

Association with spindles is a good clue to the identity of vertex activity, although even this is imperfect, since high-frequency rhythmic epileptiform activity can occasionally be seen. This pattern is most common in younger patients, so the chance occurrence of vertex epileptiform plus central alpha-range rhythmic activity has to be quite uncommon.

K-complexes (Figure **4-16**) are the fusion of a vertex with a sleep spindle. If K-complexes are seen and the vertex component has the same general appearance as the midline waves under question, the activity is most likely to be vertex than epileptiform.

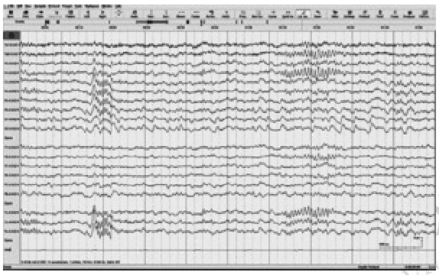

Figure 4-16:

Sleep Spindles

Sleep spindles (Figure **4-17**) are also not present at birth, but begin to appear consistently at about 2 months. The early sleep spindles are often prolonged and have an

appearance different from adult spindles, in that that they have a sharp negative peak and rounded base. They are also frequently asynchronous or asymmetrical. After 18 months of age, the majority of spindles should be synchronous. By 2 years of age, the general appearance of the sleep spindles is the same as in adults.

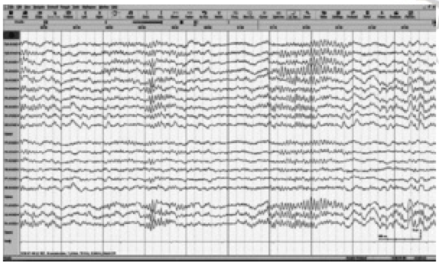

Figure 4-17:

Prominent sleep spindles are seen in this patient (same patient as for the previous figure).

Cone Waves

These high voltage occipital cone-shaped waves may be seen in the occipital regions in infancy.

Variants and Transients

Overview

Variants and normal transients are a frequent accompaniment to an otherwise typical EEG (see Tables 4-10, 4-11, and 4-12). Unfortunately, they can be confused with epileptiform or other abnormal EEG activity. This section describes some of the more important transients and variants that are certainly not considered pathologic.

Table 4-10 Normal EEG Patterns and Variants: Rhythms

Pattern	***Description***
Mu rhythm	Negative arch-shaped rhythmic activity at about 8–10 Hz. Attenuated by moving the contralateral arm. Waking.
Third rhythm (temporal alpha)	Alpha range activity in the temporal region. Seen in waking state. Recorded only in a minority of patients. Not clear what influences its appearance other than skull defect.
Slow alpha variant	Posterior rhythm of 4.5-5Hz, often notched. A sub-harmonic of the posterior dominant alpha. Seen in waking state, with eyes closed.
Fast alpha variant	Posterior rhythm of 16-20 Hz Seen in waking, with eyes closed.
SREDA	Periodic sharp activity that evolves into a rhythmic theta pattern Most often parietal in localization. Seen in older patients in the waking state
Rhythmic midtemporal theta of drowsiness	Sharply contoured theta trains in the temporal and central regions. Seen in drowsiness or relaxed wakefulness
14 & 6 positive spikes	Sharply contoured waves of these frequencies in brief trains. Both frequencies may not be seen, but are sometimes seen together. Posterior predominance. Seen in drowsiness and light sleep
6 Hz (Phantom) spike-and-wave	Low voltage spike-wave complexes that are single or in brief bursts. Have a posterior and mid-parietal predominance. Seen in drowsiness.

Table 4-11 Normal EEG Patterns and Variants: Transients	
Transient	***Features***
Mu—single transients	Fragments of the Mu rhythm. Most common in drowsiness.
Positive occipital sharp transients of sleep (POSTS)	Irregular positive waves from the occipital region. Have a similar appearance to lambda waves Seen in sleep.
Lambda waves	Positive occipital waves, look like POSTS. Seen in waking, when viewing a scene or image. Attenuated by eye closure.
Wicket spikes	Sharply contoured waves from the temporal region. May represent fragments of the third rhythm. Seen in drowsiness and light sleep. More common in older patients.
Phantom spike-waves	Low-voltage spike-wave complexes that are single or in brief bursts. Have a posterior and mid-parietal predominance. Seen in drowsiness.
Benign sporadic sleep spikes (BSSS)	Small spike-like potentials in the fronto-temporal regions, typically shifting between the two sides. Seen in drowsiness and light sleep. Also known as small sharp spikes (SSS) and benign epileptiform transients of sleep (BETS)
Frontal mittens	Mitten-shaped complex formed from the fusion of a sharp alpha or theta transient with a delta wave. Seen in sleep, especially stage 2.

Table 4-12 Prevalence of Particular Patterns Depending on State.	
State	***Patterns typical of this state***
Waking and drowsiness	Mu Third rhythm Slow alpha variant Fast alpha variant Rhythmic midtemporal theta of drowsiness 14 & 6 positive spikes Lambda waves Phantom spike-waves SREDA
Sleep	Mittens POSTS Wicket spikes BSSS

14 & 6 Positive Spikes

14 & 6 positive spikes are sharply contoured positive waveforms seen mainly in the posterior temporal region, but have a widespread distribution (see Figure **4-18**). They appear predominantly in drowsiness and light sleep. The appearance is of a train of waves at about 14 or 6/sec, although both frequencies may not be seen in the same recording epoch or in the same patient. A prolonged recording may be needed to see both frequencies. The 6/sec pattern predominates in younger children, whereas the 14/sec predominates in older children.

Figure 4-18:

Both 14 and 6 Hz positive spikes are seen in this recording.

Reports have associated the 14 & 6 pattern with a variety of pathologic conditions, but these associations are weak and the incidence is not clearly different from the general population (Drury, 1989). Therefore, this should be considered to be a normal variant if the rest of the recording is otherwise normal. Its presence should be mentioned in the body of the report, and should probably be mentioned in the impression for later consideration.

Metabolic encephalopathies, such as hepatic failure, may have an increased incidence of 14 & 6, but the background is abnormal with slowing and often triphasic waves.

BSSS (Benign Sporadic Sleep Spikes)

Benign sporadic sleep spikes are very small spike-like potentials that occur in the temporal or frontotemporal regions during drowsiness and light sleep (see Figure **4-19**). The duration is less than 50 msec with an amplitude usually less than 50 μV (but they may look larger in long-distance derivations). They may be monophasic, biphasic, and occasionally polyphasic. They may also have a small after-going slow wave. BSSS are usually differentiated from epileptiform spikes by small amplitude, short duration, tendency to shift from side to side, occasional oblique dipole with negativity in one hemisphere and positivity in another hemisphere, and otherwise normal EEG background. However, the most reliable distinguishing feature is disappearance in deep sleep, while true epileptiform discharges are usually increased in deeper sleep. BSSS is also called small sharp spikes (SSS) and benign epileptiform transients of sleep (BETS).

Figure 4-19:

This particular BSSS discharge had a dipole with negativity in the left frontotemporal region and positivity in the right temporoparietal region.

Lambda Waves

Lambda waves are positive waves that are present when viewing a scene or complex image (see Figure **4-20**). The waves are blocked by eye closure. These waves resemble POSTs. This pattern is seen in the waking state from the occipital region. The pattern is completely normal. The lambda waves may be mistaken for occipital spikes; however, their positive polarity and blocking with eye closure make this clearly not epileptiform.

Figure 4-20:

Positive lambda-shaped waves are seen posteriorly.

Lambda waves indicate visual exploration. Their label comes from their resemblance to the Greek lowercase letter *lambda* (λ). Lambda waves are normal and should be commented on in the body of the report but need not be mentioned in the interpretation.

Mittens

Mittens are seen only in sleep and consist of a partially fused vertex wave and sleep spindle. The last wave of the spindle is superimposed on the rising phase of the vertex wave (see Figure **4-21**). This voltage summation gives the last spindle wave a faster and higher amplitude appearance, which may simulate a spike. Mittens are seen only in sleep.

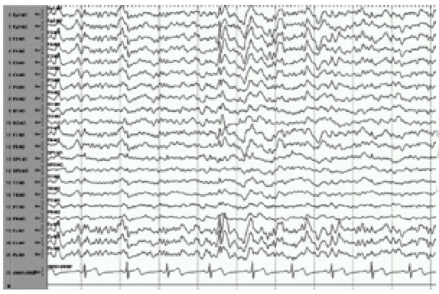

Figure 4-21:

Typical mittens are seen near the middle of the tracing.

The name comes from the appearance of a hand mitten, the thumb being the fused spindle wave and the hand being the vertex wave. Mittens are normal, but can be confused with a spike-wave pattern, especially if the spindle component has a fast appearance. Careful inspection of the record usually allows the reader to dissect out the vertex and spindle components of the wave.

Mu

Mu rhythm (Figure **4-22**) is seen in the waking state, and is a negative arch-shaped rhythm of about 8–10 Hz. The potentials are most prominent at C3 and C4. Mu activity is often sharp. Its sharpness and amplitude are increased in the presence of a skull defect over the central region. In drowsiness, the Mu rhythm may be broken up into fragments that can easily be over-interpreted as abnormal epileptiform activity. Mu is very often asymmetric or even unilateral. The absence of Mu activity on one side is not abnormal, unless there is very frequent Mu activity on one side and none on the other side. The key to identification of Mu rhythm is blocking by movement of the contralateral arm. Even contemplating movement can produce this change.

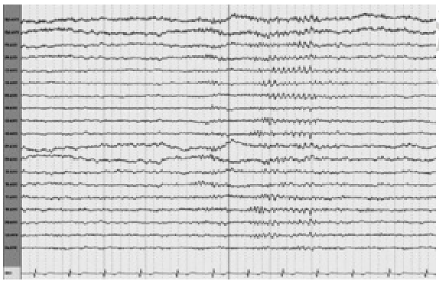

Figure 4-22:

Phantom Spike-Waves

These low voltage 6 Hz spike-and-wave discharges can be single or in brief trains and occur typically in drowsiness. The classical benign variant has biposterior predominance, particularly at Pz. They tend to occur mostly in young women. Figure **4-23** shows phantom spike-waves with reversal of polarity at Pz.

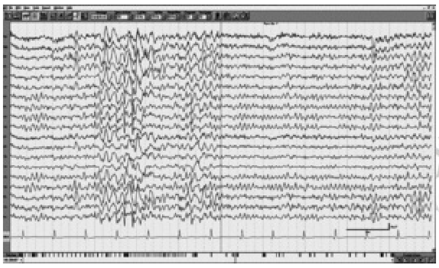

Figure 4-23:

6-per-sec phantom spike-wave is seen.

Positive Occipital Sharp Transients of Sleep (POSTS)

Positive occipital sharp transients of sleep (POSTS) are surface positive potentials seen from the occipital region, maximal in derivations of O1 and O2 (see Figure **4-24**). They look somewhat like lambda waves, but are present only in sleep, whereas lambda waves are only seen in the waking state with the eyes open. POSTS are prominent through stage 2 sleep and disappear in deeper stages. POSTS can appear as single waves or in trains.

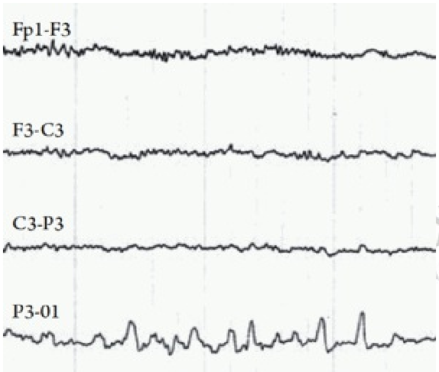

Figure 4-24:

Positive transients are seen occipitally in sleep.

POSTS are less commonly seen in patients who are blind or who are severely visually impaired. One hypothesis is that POSTs represent replay of visual information.

POSTS are not seen in every patient and have no diagnostic significance, unless they appear only from one hemisphere. Even in this circumstance, asymmetric POSTS are

unlikely to be the only abnormality on the EEG.

Rhythmic Midtemporal Theta of Drowsiness

Rhythmic midtemporal theta of drowsiness (Figure **4-25**) was once called *psychomotor variant*, although this term has been discarded. This pattern consists of trains of sharply contoured notched waves in the theta (6 Hz) range in the temporal region. The pattern may be bilateral, but most often seems to start on one side, then within a short time develops on the opposite side.

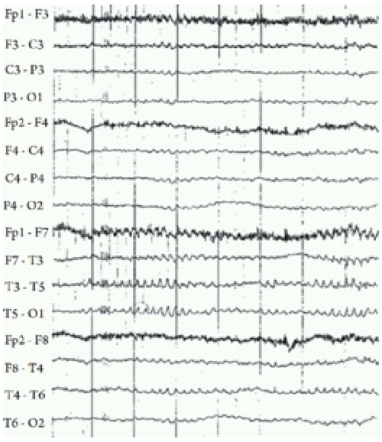

Figure 4-25:

The rhythmic theta is most evident on the lower part of the page.

Rhythmic midtemporal theta of drowsiness can be distinguished from epileptiform activity by the following:

- Normal background before and after the rhythm;
- Absence of a progressive change in frequency that would be typical of epileptiform activity;
- Presence in drowsiness but not sleep.

This pattern is normal, but may be more likely in some patients with structural lesions.

Slow Alpha Variant

The posterior dominant rhythm in most adults is 8.5–11 Hz. In some patients, there can be a sub-harmonic of the posterior rhythm at 4–5 Hz. The slower frequency is typically notched. The sub-harmonic can be misinterpreted as a slow background in the theta range. Differentiation of slow alpha variant (Figure **4-26**) from a pathologically slow background can be made by the following features:

Figure 4-26:

The posterior rhythm is approximately 5 Hz, some of these have a notched appearance, revealing the faster native frequency.

- Notched appearance of the rhythm;
- Attenuation of the rhythm with eye opening.
- Stereotypic appearance of the background of the slow alpha variant as opposed to polymorphic appearance of pathologic slow activity of encephalopathy;
- Appearance of normal frequency of the posterior dominant rhythm elsewhere in the recording, sometimes intermixed with the slow variant.
- Normal frontal and cerebral activity with slow alpha variant as opposed to slowing associated with encephalopathy.

Fast alpha variant

Fast alpha variant (Figure **4-27**) is characterized by an otherwise-normal posterior dominant rhythm that appears as a harmonic of the native rhythm, appearing at twice the native frequency (16–20 Hz), which is in the beta range. The fast alpha variant is easy to interpret as normal, since there is not the slowing that is more typical of pathology.

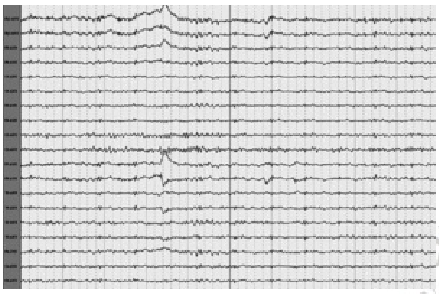

Figure 4-27:

The posterior rhythm is approximately twice the normal posterior alpha frequency.

SREDA

Subclinical rhythmic electrographic discharge of adults (SREDA) is rhythmic sharp activity that appears in some older patients in the awake state (Figures **4-28a** through **4-28d**). Typically, periodic sharply contoured waves evolve into a rhythmic theta pattern.

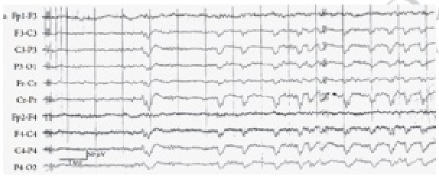

Figure 4-28a:

This sequence of images (4-28a–4-28d) shows evolution of SREDA.

Figure 4-28b:

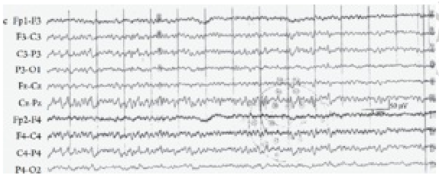

Figure 4-28c:

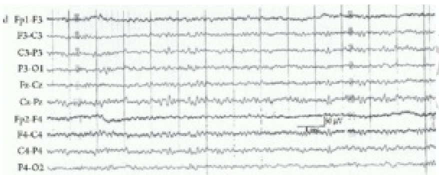

Figure 4-28d:

Although SREDA resembles an ictal discharge, there is no clinical change during the discharge.

SREDA can be easily confused with seizure activity. Some differentiating features are:

- Occurrence only in the waking and drowsy states;
- Intact consciousness during the discharge,
- Abrupt onset and termination of the discharge.

Wicket Spikes and Third Rhythm

Wicket spikes are sharply contoured waves that are most prominent from temporal regions during drowsiness and light sleep.

Wicket spikes can be differentiated from pathologic spikes by:

- Absence of a following slow wave;
- Normal background activity;
- Occurrence in a series of waves at 6–10 Hz.

Wicket spikes are more common with increasing age.

Figure **4-29** shows also the so-called *third rhythm*. This is a mid-temporal rhythmic activity that is related to wicket spikes, but has an origin in association with the posterior dominant alpha-range activity and Mu rhythm. Third rhythm was thought to be the third brain idling rhythm, besides these other two.

Figure 4-29:

Both wicket spikes and rhythmic temporal theta activity (third rhythm) are seen.

Non-cerebral Potentials

Artifacts can be biological or electrical. Unfortunately, electrical artifacts can predispose to enhanced perception of biological artifacts.

Biological

Biological artifacts are generated by the body, but not by the brain. They can be confused with electrocerebral activity, and if so are frequently interpreted as slowing or spikes.

Eye Movement

The eye is electrically charged with the cornea positive relative to the fundus, so any movement of the eye results in potentials that can be recorded from anterior leads. These potentials can occasionally be mistaken for frontal lobe activity.

Vertical eye movements: Downward gaze results in the positive cornea moving away from the frontal lobe, so negativity is seen in frontal leads. The reverse is true for upward gaze. Since the eyes move up and down together, the potentials from the two sides are synchronous. Of course, one must remember the possibility of a prosthetic eye, producing unilateral eye movement artifact. Certain vertical eye movements have characteristic patterns, including eye blinks, eye opening, eye closure, eye fluttering.

Eye closures: Eye closure results in Bell's phenomenon, an upward deviation of the eyes (Figure **4-30**). This will be associated with a positive deflection in the frontopolar electrodes. In addition, eye closure is associated with appearance of the posterior dominant rhythm.

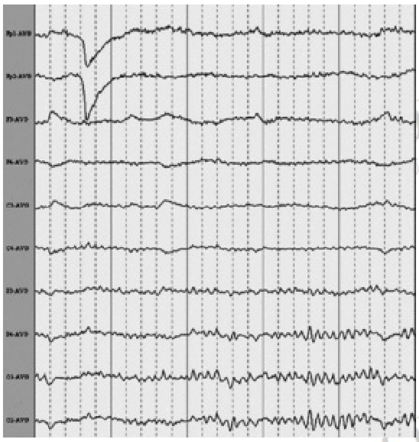

Figure 4-30:

With eye closure, there is a positive deflection at Fp1 and Fp1. The rate of return to baseline depends on the setting of the low-frequency filter. Notice the appearance of posterior dominant rhythm in conjunction with eye closure.

Eye blink: An eye blink causes the same positive potential in the frontopolar regions, but the subsequent eye opening causes a negative deflection (Figure **4-31**). The subsequent negative deflection distinguishes an eye blink from mere eye closure.

Figure 4-31:

Prominent eye blink potentials are of ocular origin, not cerebral.

With eye blinks there is a negative potential that follows the initial deep positive potential in the frontopolar electrodes. Eye blink can be more repetitive and have the appearance of frontal slow or sharp activity (Figure **4-32**).

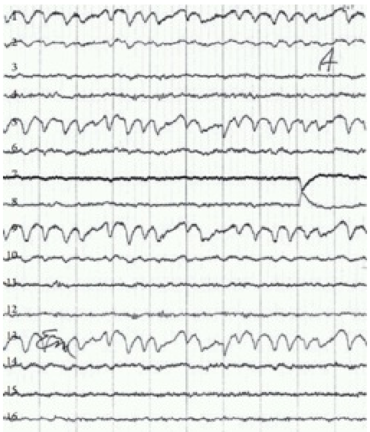

Figure 4-32:

Eye flutter can produce artifact that is even faster than normal eye blink and can be mistaken for epileptiform activity or for fast frontal beta activity (Figure **4-33**).

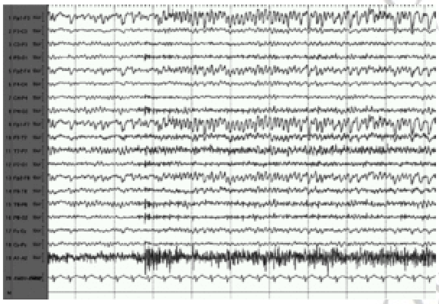

Figure 4-33:
muscle artifact shows that this is movement-related, however.

Figure **4-34** shows another example of eye flutter that occurs after the patient opens eyes, in the middle of the recording epoch.

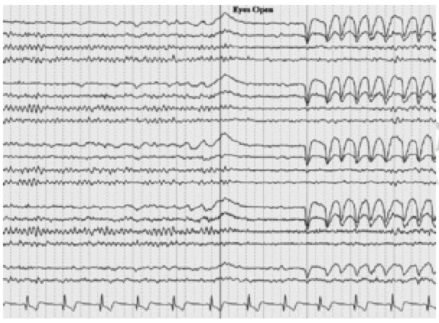

Figure 4-34:

LB montage. Left side shows waking record with eyes closed with normal posterior rhythm. This is attenuated with eye opening. Right side shows repetitive eye blinks.

Eye opening: Eye opening results in a negative potential in the frontopolar electrodes plus alteration in the posterior rhythm. The attenuation of the posterior rhythm with eye

opening and reappearance with eye closing are good clues to the presence of vertical eye movements, although the technician should indicate this phenomenon along with other patient movements. Eye closure results in restoration of the posterior rhythm. The posterior dominant frequency may be slightly faster immediately after closure. Therefore that should be measured a few seconds after eye closure.

Figure **4-34** shows a classic response to eye opening. Figure **4-35** shows a much more subtle response to eye opening.

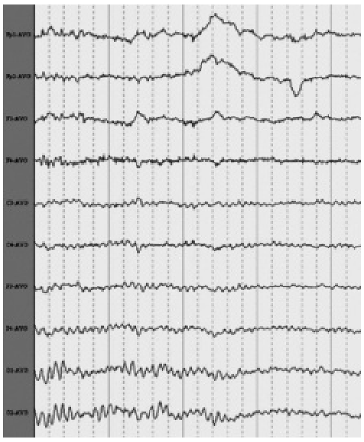

Figure 4-35:

With eye opening there is a negative potential in the frontopolar electrodes and attenuation of the posterior dominant rhythm

Lateral eye movements: Lateral gaze results in the positive cornea moving toward the temple to the side of gaze (see Figure **4-36**). For example, left gaze results in positivity at the F7 electrode, whereas there is negativity at the F8 electrode. The differential effect of lateral gaze on the two sides makes for easy identification of this as a non-cerebral potential.

Figure 4-36:

This tracing indicates eye movement to the right then to the left.

Lateral eye movements (Figure **4-37**) are often associated with lateral rectus spikes. Typical, the spike will be followed by a slower positive potential on the side to which the eyes moved.

Figure 4-37:

Each lateral rectus spike is followed by a positive potential indicating eye deviation to the side of contraction.

Differentiating eye movement from cerebral potentials is based on some basic guidelines:

- Certain eye movements such as eye blinks have a stereotypic appearance, different from frontal slow activity.
- Vertical eye movements are generally restricted to, or at least markedly predominant, in the frontopolar electrodes. This has resulted in the principle that slow wave activity restricted to the frontopolar electrodes is eye movement artifact until proven otherwise.
- Pathologic frontal slow activity tends to be associated with a slow background, with activity in the theta and/or delta range. A normal background will suggest that slow

activity restricted to the frontal region most likely represents eye movement artifact.

- Patients with marked vertical eye movements will often have prominent lateral eye movements as well, which can be easily recognized.

Eye movement monitoring: Eye movement monitoring was discussed in detail in Chapter 3 can be facilitated by an arrangement similar to that shown in Figure **4-38**.

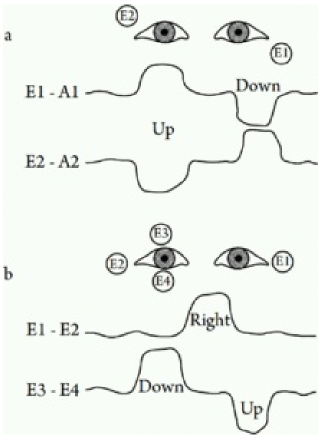

Figure 4-38:

Placement of eye leads can reveal not only eye movement and differentiate from cerebral activity but also indicate direction of movement. a: Vertical movement detection. b: Horizontal movement detection.

Figures **4-39** and **4-40** show the placement of leads for differentiation of eye movements from frontal cerebral activity:

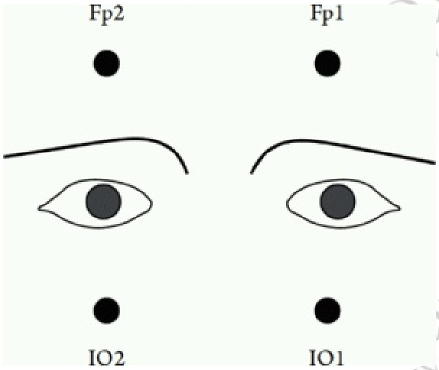

Figure 4-39:

Infraorbital (IO) electrodes in conjunction with frontopolar (Fp) leads are helpful for characterization of eye movements.

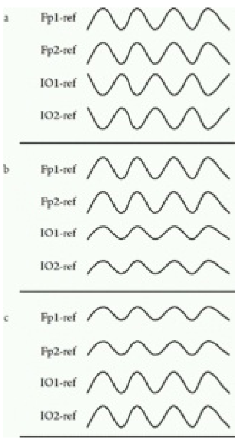

Figure 4-40:

a: Activity related to vertical eye movements. This will be of opposite polarity in the infraorbital versus the frontopolar electrodes,

b: Activity of cerebral origin. This has the same polarity in the infraorbital and frontopolar electrodes, but has lower amplitude in the frontopolar electrodes, which are closer to the frontal cortex,

c: Glossokinetic activity arising in the tongue. This has the same polarity in the infraorbital and the frontopolar electrodes, but has higher amplitude in the infraorbital electrodes, which are closer to the tongue.

Muscle Artifact

EMG activity frequently contaminates EEG recordings, and this is prominent when patients are tense, seizing, or have other reasons for increased tone of scalp muscles. EMG is often prominent from the temporal leads. Frontal and occipital leads may also be prominently involved, whereas midline electrodes will usually be least affected. EMG artifact consists of short needle-like spikes, which may occur in such frequency that they become confluent and give an appearance that resembles noise.

Some guidelines for differentiating EMG from epileptiform spikes are as follows:

- EMG is very fast, much faster than spikes. Activity recorded at the scalp that is shorter than 20 msec is highly unlikely to be epileptiform activity.
- EMG spikes are not followed by a slow wave.
- EMG is prominent in the waking state, and disappears with sleep.
- EMG spikes recur at a rate that is much faster than would be seen with repetitive spikes.
- EMG is attenuated by asking the patient to relax the jaw, open the mouth, or other maneuver.

Figure **4-41** shows a typical appearance of muscle artifact. Occasionally, muscle artifact is more restricted, and may even arise from a single motor unit, particularly in the midtemporal region (see Figure **4-42**).

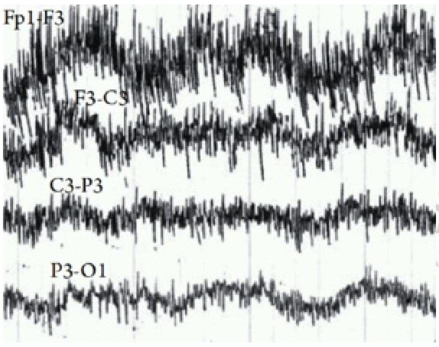

Figure 4-41:

Figure 4-42:

Muscle artifact arising from T7. As the patient relaxed more, this artifact became restricted to a single motor unit, with a characteristic appearance in the lower figure.

Although muscle artifact can be filtered using the high-frequency filter, the unfiltered EEG should always be viewed first. The high-frequency filter may distort the appearance of muscle artifact such that it starts to appear cerebral in origin. Figure **4-43** provides an example.

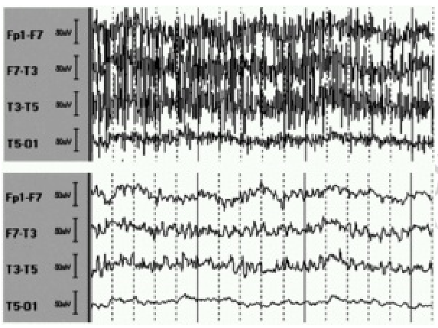

Figure 4-43:

The top segment has a high-frequency filter setting of 70 Hz, whereas the lower segment has a high-frequency setting of 15 Hz. Without looking at the unfiltered EEG, the muscle activity may be misinterpreted as beta activity.

Glossokinetic Artifact

The tongue is polarized, with the tip negative in comparison to the back. Movement of the tongue is common in the waking state, and can occasionally be mistaken for pathologic frontal slow activity. This is potentially even more problematic in a comatose patient who is having tongue movements. Glossokinetic artifact can be differentiated from slow activity in the following ways:

- Glossokinetic artifact usually disappears in drowsiness and light sleep.
- Glossokinetic artifact is associated with activities such as speaking, chewing, swallowing.
- Glossokinetic artifact is often concurrent with EMG artifact of the frontalis and temporalis muscles

If there is still doubt about identification, then electrodes can be placed below the eyes. The patient is asked to make lingual movements such as "la la la" and the potentials observed, glossokinetic artifact shows higher voltage at the infraorbital electrodes than at the frontopolar electrodes. Cerebral activity will be higher in voltage in the frontopolar electrodes. Identification of glossokinetic artifact is much better if the technician recognizes the problem and is able to perform these maneuvers during the study.

Combinations of muscle and glossokinetic artifact produce very characteristic patterns. Some are displayed in Figures **4-44**, **4-45**, and **4-46**. The patient is a young woman who had episodes of tongue clicking after arousal. The slow waves between the bursts are glossokinetic potentials. The EMG bursts are related to temporalis muscle contraction. Figure **4-47** is the same epoch with different filter settings, and the non-epileptiform character is more evident.

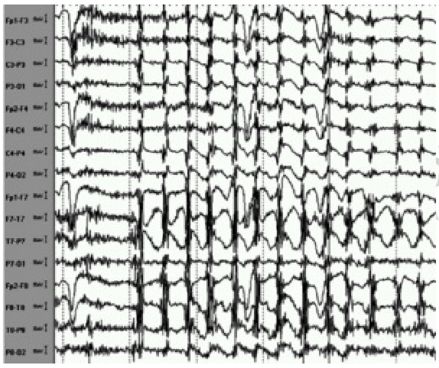

Figure 4-44:

The high-voltage muscle potentials are related to temporalis muscle contraction. The slow potentials are glossokinetic, related to tongue movement.

Figure 4-45:

Movement of the tongue produces a slow deflection on which is superimposed muscle artifact.

Figure 4-46:

Chewing produces prominent muscle artifact, especially well seen from temporal leads.

Figure 4-47:

Same recording as in Figure **4-46**, but with filter settings to reduce much of the muscle artifact.

Toothbrush Artifact

During long-term monitoring a variety of artifacts are evident. When the patient is observed in the video unit, behavioral correlates are obvious. In the absence of observation, the potentials shown in Figure **4-48** with brushing of teeth could be misinterpreted as seizure activity.

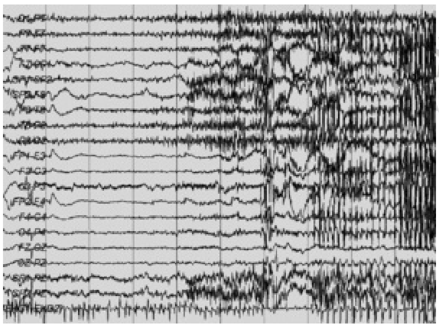

Figure 4-48:

Rapid activity that is representative of approximately 7 Hz movement plus superimposed muscle activity.

Mistaking this discharge for seizure would be most likely if the behavior is not observed, as with long-term outpatient monitoring, where limited behavioral information is available.

EKG Artifact

Electrocardiogram (EKG) artifact is seen mainly on referential montages (see Figure **4-49**). Increased inter-electrode distance predisposes to EKG artifact. Differentiation from electrocerebral artifact is most obvious if a special EKG channel is recorded, but even in the absence of this, the regular nature of the QRS complex and the distribution of the sharp activity make the source evident.

Figure 4-49:

Artifact caused by cardiac electrical activity with an interval of approximately 1/sec.

Pulse Artifact

Pulse artifact is due to movement of the electrode leads overlying the scalp blood vessels. Pulsation of a small artery results in movement of the electrode disc, which affects the electrode-gel connection and, if large enough, can even move the electrode leads. The appearance is an irregular delta wave that is time-locked to EKG, except that there is a delay between the QRS complex and the pulse.

Pulse artifact can be differentiated from pathological slow activity by the following features:

- The artifact usually localizes over one electrode.
- The artifact is time-locked to the EKG but with a delay.

- The background is otherwise normal.

Initial inspection could mistake pulse artifact (Figure **4-50**) for polymorphic delta activity, but in this situation the background is usually abnormal, with slowing and disorganization. If there is still doubt, examination of the scalp by the technician can be revealing.

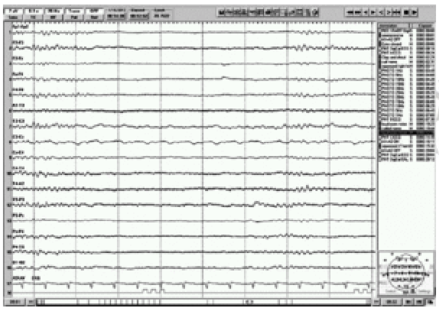

Figure 4-50:
Note EKG at the Bottom of the Page.

Electrical

Electrical artifact includes potentials that do not originate in the electrical activity of the body. Electrode leads can be an origin of the artifact. In addition, induced electrical current in electrode leads by nearby electric lines is a major source of artifact.

Electrodes and Leads

Electrode leads can be a source of artifact especially if there is instability in fixation of the electrode and high impedance. Movement of the electrode results in changes in the junction potential. The discharge of the junction potential results in a potential that can be mistaken for a spike discharge and is termed an *electrode pop* (Figure **4-51**). The appearance is of a brief spike, followed by a gradual decay to baseline. During the spike, the responsiveness of the amplifier can be briefly impaired, so the EEG background immediately following can be transiently suppressed.

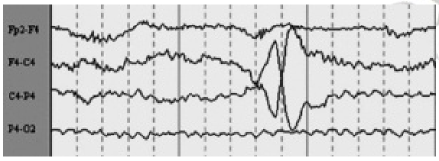

Figure 4-51:

This potential is focal at C4, with no involvement in any other electrode. Electrode impedance measurements obtained at the beginning of the study indicate that C4 impedance was elevated at 9K.

Electrode pops are reduced by having good junction between the electrode and scalp with sufficient gel. Also, stabilization of the electrode leads is helpful to minimize movement of the discs.

The example in Figure **4-52**, obtained from the same patient as in Figure **4-51**, shows sharply contoured slow activity that has no field, restricted to C4. This makes it likely to be artifactual.

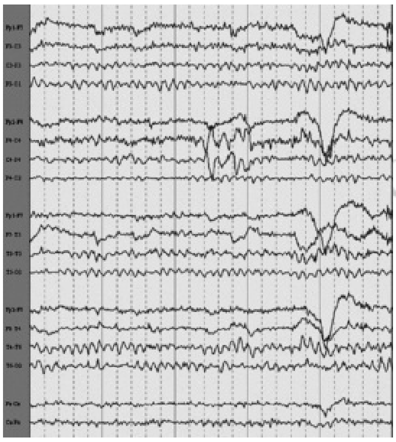

Figure 4-52:

The abnormality near the center of the recording is due to electrode artifact at C4 rather than due to cerebral abnormality.

Machine Artifact

Machine artifact is especially prominent in the ICU. This is high-frequency stereotyped activity that is seldom confused with cerebral activity. The frequency can be the frequency of line power, but also can be at faster or slower frequencies, since mechanical devices are not time-locked to line power activity. Most mechanical devices are

driven by DC power, although the power comes from AC power through a transformer; therefore, the artifact is the frequency of the motor, rather than the frequency of line power. Motors are in ventilators, IV pumps, hospital beds, and other electrical monitoring devices.

Machine artifact can be reduced by:

- Minimizing electric equipment nearby the EEG laboratory;
- Adequate grounding of the patient;
- Adequate grounding of the EEG machine.

60-Hz Artifact (Line Power)

60-Hertz interference is a result of induction from surrounding electronic circuits that are not directly attached to the patient. Movement of current through power lines produces a magnetic field that is created around the line. This magnetic field causes current to flow in electrode leads by induction, a fundamental property of electronic devices. The induced current flow will reverse at 60 Hz, since the magnetic field will also reverse at 60 Hz. Therefore, there is 60 Hz contamination in the electrode leads without any direct connection between the power lines and the EEG leads. This stray inductance is a major cause of electrical interference. It is most likely to appear when there is impedance imbalance. It is also most problematic in the ICU environment.

Figure **4-53** shows the right parasagittal portion of the longitudinal bipolar montage. Midway through this epoch, the air bed is unplugged and the high-frequency activity disappears. The focal nature of the 60 Hz artifact raises the possibility of high impedance at P4.

Figure 4-53:

The electric air pump on the bed was the source of this artifact. When unplugged, the artifact disappeared.

Focal 60 Hz artifact should always raise the possibility of focal high impedance (Figure **4-54**). In this example the very fast activity at C4 without appearance in other leads suggests that this is not electrocerebral.

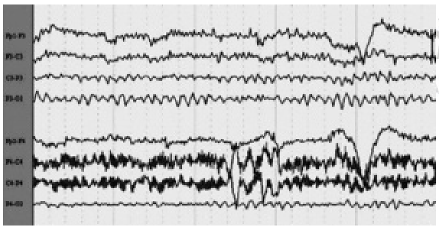

Figure 4-54:

Lower part of the recording shows 60 Hz artifact.

Phone Artifact

Telephones commonly ring, especially when patients are being monitored or examined. Figure **4-55** is an example of the electrical artifact of the ringing of a phone. The stereotypic rhythmic activity lasting just a few seconds is the ringing of the phone.

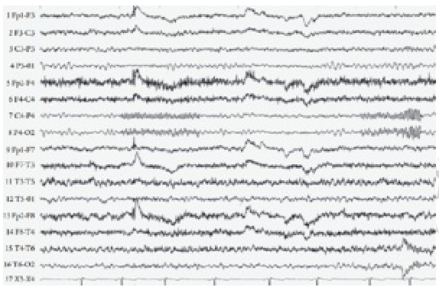

Figure 4-55:

Electrical artifact from ringing of a desktop phone.

Movement Artifact

Movement artifact is due to disturbance of the electrodes and/or leads. Electrode gel is a malleable extension of the electrode, and minor head movement produces little effect on the electrode-gel-scalp attachment. However, movement sufficient to disturb the connection results in charge movement between the electrode and gel and scalp, which is recorded as EEG (Figure **4-56**). Differential amplification does not remove this artifact because the lead artifact affects the recording from a single electrode.

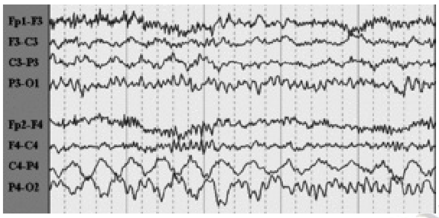

Figure 4-56:

Movement artifact at P4, resembling focal slow wave activity.

Movement artifact is also produced by movement of the leads. A small amount of current flows through the electrode leads, and while this current is miniscule compared to most electrical circuits, there is resistance of the leads and capacitance between the leads. Movement of the leads results in disturbance of the capacitance. The built-up charge can dissipate with loss of the capacitance, and this too is recorded as EEG.

How to Avoid Environmental and Machine Artifacts

Electrical artifact, including machine and 60-Hz potentials, can be minimized by the following:

- Recording in an electrically quiet environment, certainly not possible for patients in the ICU;
- Avoidance of ground loops;
- Disconnection of all non-essential electronic equipment from the patient;
- Minimizing the length of the exposed leads;
- Turning off lights and other equipment in proximity to the patient;
- Use of differential amplifiers (which is typical with modern equipment) and equal electrode impedances;
- Use of the 60-Hz filter, as a last resort.

Abnormal Non-epileptiform EEG

Overview

Abnormal EEG activity includes ictal and epileptiform abnormalities and non-epileptiform abnormalities. Non-epileptiform abnormalities will be discussed first. Table 4-13 outlines some of the important non-epileptiform abnormalities.

Table 4-13 Abnormal Non-epileptiform EEG

Class	***Type***	***Implication***
Slow	Focal slow activity	Focal rhythm disturbance usually due to a focal structural lesion.
	Generalized asynchronous slow activity	Generalized cerebral dysfunction, as in encephalopathy with a broad differential diagnosis
	Generalized or regional bisynchronous slow activity	Usually due to encephalopathy, with typical manifestation being frontal intermittent rhythmic delta activity (FIRDA) or occipital intermittent rhythmic delta activity (OIRDA).
Attenuation	Focal attenuation	Due to either focal reduction in cortical activity or accumulation of fluid over the cortex, e.g., subdural hematoma.
	Generalized attenuation	Global reduction in amplitude usually due to diffuse loss of cortical activity. Bilateral fluid collection over the cortex is possible.
Increase activity	Focal increase in activity	Most common is skull defect that reduces the attenuation of faster frequencies, a *breach rhythm*.
	Generalized increase in activity	Usually due to encephalopathic disorders, especially excess diffuse beta activity most commonly seen with benzodiazepines.
Other abnormal patterns	Non-epileptiform periodic discharges	Periodic lateralized epileptiform discharges (PLEDs) are often seen in HSV encephalitis, and in this circumstance are either unilateral or independent bilateral. Hypoxic encephalopathy can produce bilateral independent epileptiform discharges (BIPLEDs) or generalized periodic epileptiform discharges (GPLEDs).
	Alpha-theta coma	Patients with coma from a variety of reasons can have alpha coma, theta coma, or alpha-theta coma. The terms indicate the predominant frequencies and tend to portend a poor prognosis.
	Spindle coma	Appearance of spindles in coma, but these are different from sleep spindles. Prognosis is less grave than some other patterns.
	Burst suppression	Severe encephalopathy often seen with hypoxic encephalopathy or other severe cerebral damage or from deep sedation with certain meds.

The most common non-epileptiform abnormality is slowing. Generalized slowing is usually due to diffuse encephalopathy, with a broad differential diagnosis. Many patients have multifactorial etiology for the encephalopathy. Focal slowing is usually due to a structural abnormality; features of the slowing cannot distinguish between causes such as tumor, stroke, mass lesion, and so on.

Amplitude abnormalities are less common than slowing and can be focal or generalized. Generalized suppression indicates encephalopathy and focal suppression indicates a focal structural lesion.

Periodic patterns are often non-epileptiform, although this is a controversial area in EEG. Some investigators believe that periodic patterns are all potentially epileptogenic, whereas others believe that the periodic patterns can indicate dysfunction of the brain without necessarily being epileptogenic.

Slow Abnormalities

Overview

Slowing can be generalized or focal or regional. Focal slowing is easier to identify than generalized slowing, since comparison of the slowing with normal background facilitates recognition. Generalized slowing must be distinguished from normal slow activity such as drowsiness or sedation.

Focal slowing is most commonly seen with structural lesions. Generalized slowing is most commonly seen with encephalopathy.

Regional slowing is uncommon, and usually manifests as intermittent rhythmic delta activity. Although this might be considered focal, it is bihemispheric, so should be considered regional.

Focal Slow Activity

Focal slow activity (Figure **4-57**) usually indicates a focal subcortical structural lesion. The slow activity typically has an irregular, polymorphic appearance, hence the name *polymorphic delta activity* (PDA). In general, the area of the slow activity is overlying the location of the structural lesion, but the anatomic correlation is not always exact.

Figure 4-57:

There is generalized (diffuse) slowing of the background with prominent focal slow activity over the right hemisphere. This indicates a right hemisphere structural lesion in addition to a generalized encephalopathy.

The differential diagnosis of focal irregular slow activity is large, with some of the possibilities including:

- Tumor;
- Stroke—ischemic or hemorrhagic;
- Infection—abscess or encephalitis;
- Trauma—contusion or hematoma;
- Epileptic focus—irregular slow activity may be associated with an epileptic focus in the absence of structural lesion;
- Transient focal abnormality may be seen in migraine, ischemia, or postictal dysfunction after a focal seizure.

Unfortunately, one cannot usually be definitive about the etiology of the slow activity from the appearance. While additional historical information may help the analysis, the diagnosis of focal structural lesions rests largely with imaging studies.

One form of focal slow activity, temporal intermittent rhythmic delta activity (TIRDA), has a strong association with seizure activity (see Figure **4-58**).

Figure 4-58:

Rhythmic delta activity in a 48-year-old man with right temporal lobe epilepsy. This activity is present only intermittently.

Generalized Asynchronous Slow Activity

Generalized asynchronous slow activity (Figures **4-59** and **4-60**) is extremely non-specific. It can be predominantly in the theta or delta range. It usually indicates encephalopathy. Slow activity in the theta range indicates mild or moderate encephalopathy, whereas slow activity in the delta range means more severe encephalopathy.

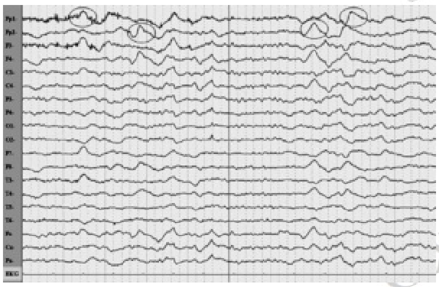

Figure 4-59:

The EEG shows mostly asynchronous generalized slow activity. Specific delta waves seen on one side not the other are circled. The patient is a 74-year-old woman with anoxic brain injury.

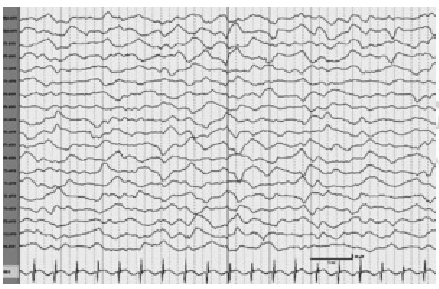

Figure 4-60:

In this example, the asynchronous slow activity is more pronounced.

Expected normal background for age influences the interpretation of the slow activity, since slow activity is normally present in drowsiness and sleep at all ages and in the

awake state in children. In these situations, there should be caution in interpretation of slow activity—we should only read it as abnormal if the pattern is inconsistent with any normal stage of the sleep-wake cycle.

Generalized or Regional Bisynchronous Slow Activity

Bisynchronous slow activity can be generalized or regional. Even when it is generalized, it usually predominates in one region of the brain. This type of activity is often, but not always, rhythmic and intermittent. The most important is frontal intermittent rhythmic delta activity (FIRDA) (Figure **4-61**) and occipital intermittent rhythmic delta activity (OIRDA) (Figure **4-62**).

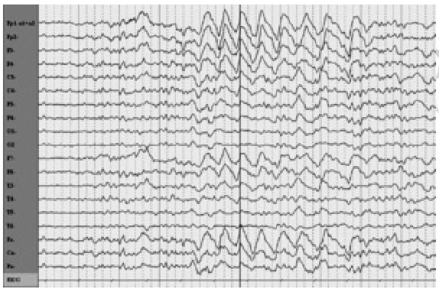

Figure 4-61:

Frontal rhythmic delta is seen from both hemispheres.

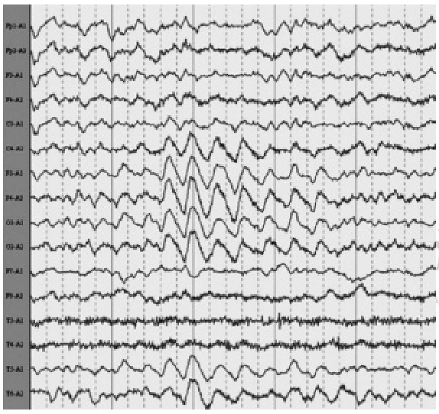

Figure 4-62:

Occipital rhythmic delta is seen bilaterally in this child.

FIRDA is rhythmic activity in the delta range that is synchronous on the two sides. This is either limited to the frontal region or generalized with frontal predominance. The frequency is most often about 2.5–3 Hz. It can be seen in a wide variety of conditions, but more commonly is due to diffuse cerebral dysfunction than due to deep structural lesions.

The differential diagnosis includes:

- Metabolic encephalopathies;
- Degenerative disorders and other conditions affecting cortical and subcortical gray matter;
- Deep midline tumors;
- Normal.

FIRDA is normal in drowsiness and with hyperventilation at any age and in waking in children.

Children have intermittent rhythmic delta activity that tends to be centered over the occipital region rather than the frontal region, hence occipital intermittent rhythmic delta activity (OIRDA).

Some neurophysiologists prefer the term *PIRDA* for posterior-IRDA, finding the acronym OIRDA hard to pronounce. The clinical implications of OIRDA in children are considered identical to those of FIRDA in adults. However, OIRDA was reported to be associated with epilepsy in children, particularly generalized epilepsy. There may be subtle spikes embedded in the occipital rhythmic activity in children with childhood absence epilepsy. Generalized absence and generalized tonic-clonic seizures were more likely in children with OIRDA than in control subjects.

Generalized Synchronous Slow Activity

Slowing of the waking posterior dominant rhythm (Figure **4-63**) is change of the posterior alpha-range activity to less than 8.5 Hz. Slowing to less than this level is almost always abnormal in adults. The most common degree of slowing is in the theta range, with slowing in the 6.5–8 Hz range. Slowing to less than this is associated with higher levels of disorganization of the background. Interpretation is non-specific, but generally is due to encephalopathy or dementia.

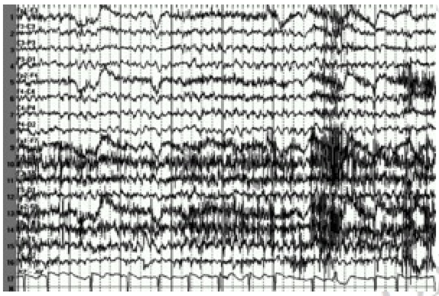

Figure 4-63:

Slowing superimposed on an otherwise normal background is a common finding and may be seen in patients with mild cognitive changes and in vascular disease. However, this is not a specific pattern and should not be interpreted as such.

Slowing of the background replacing normal background activity suggests moderate encephalopathy. The neurophysiologist must ensure that the patient is in the awake state, in this circumstance, to differentiate encephalopathy from a drowsy pattern. When the technician knows that the clinical question is encephalopathy, the patient should be stimulated to gain a good waking record, if possible, and notation made if this cannot be achieved.

Interpretation of generalized slow activity (*Figure **4-64***):

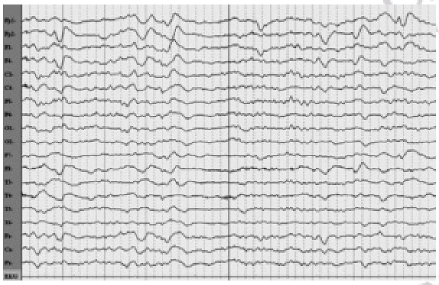

Figure 4-64:

Slowing is diffuse and there is no posterior dominant rhythm.

- Slowing of the posterior dominant rhythm is seen in dementia and in mild encephalopathy.
- Theta superimposed on an otherwise normal background can indicate a mild encephalopathy but is also seen in patients with vascular disease without cognitive changes.
- Theta and delta slowing of the background are suggestive of moderate encephalopathy.
- Diffuse delta slowing is suggestive of severe encephalopathy. Triphasic waves seen with this background can be seen in hepatic encephalopathy but are not specific for this, and can be seen in other metabolic encephalopathies and hypoxic encephalopathy.

Amplitude Abnormalities

Overview

Amplitude abnormalities can be focal or generalized. Focal amplitude abnormalities include focal suppression or increase in amplitude. Generalized amplitude abnormalities include global suppression or increase in amplitude.

Attenuation/Suppression

Focal Attenuation

The term *attenuation* indicates decreased amplitude of one type of activity (such as activity in a certain frequency) or of all activity. Focal attenuation (Figure **4-65**) usually indicates a focal cortical lesion (such as infarct) or dysfunction (such as ischemia or postictal effect), but may also result from an increased distance between the cortex and the recording electrode, such as may be seen from scalp edema, subdural hematoma, and occasionally from dural-based tumors, such as meningiomas.

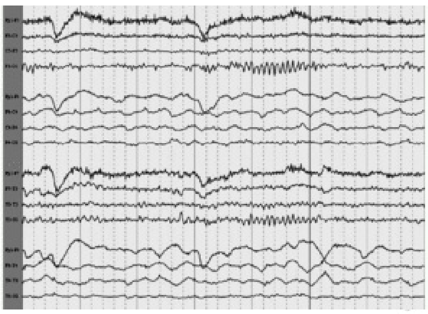

Figure 4-65:

The posterior dominant rhythm is attenuated on the right side after a seizure.

The recording shown in Figure **4-66** is from a patient with head injury and subsequent infarction.

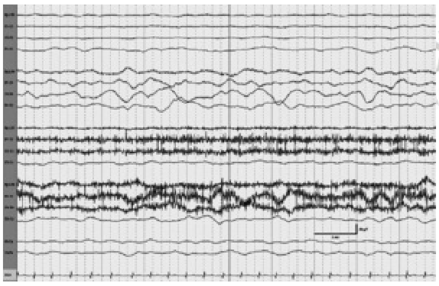

Figure 4-66:

Generalized suppression with focality, worse on the left. Due to head injury with subsequent infarction and edema.

Focal suppression will usually involve multiple electrodes. Focal suppression that is confined to one electrode is more likely to be due to smear of electrode paste, or some other artifact that affects the recording system. When this is ruled out, focal suppression is usually due to one of the following:

- Focal cortical dysfunction;
- Extracranial mass lesion;
- Intracranial mass lesion.

Focal cortical dysfunction is the cause of prime importance to the neurologist; however, it may be difficult to distinguish from loss of signal due to non-cerebral mass lesion. Extracranial mass lesion such as scalp hematoma can result in attenuation of the background. Similarly, intracranial hematomas such as subdural hematoma may also result in attenuation of the background over the area of the cortex.

Differentiation of cortical from extra-cerebral suppression can be difficult, but some general guidelines exist:

- Cortical defects result in disturbance of the background rhythms with a tendency to slowing, whereas extra-cerebral causes result in reduction in amplitude but with a pattern that looks like the rest of the brain if the gain is increased.
- Cortical defects usually cause abnormalities in frequency of adjacent tissue, resulting in a spread of suppression or slowing across adjacent areas, whereas extra-cerebral lesions result in normal potentials from cortex not underlying the defect.
- Cortical defects are more likely to be associated with superimposed epileptiform abnormalities.

Generalized Attenuation/Suppression

The term *suppression* is a more severe attenuation, and is usually used to indicate complete or almost complete disappearance of EEG activity. Generalized attenuation or suppression of the background can happen because of three reasons:

- Decreased synchronicity of cortical activity;
- Decreased cortical activity;
- Excessive fluid or tissue overlying the cortex.

Decreased synchronicity of cortical activity may occur in an awake, alert state, and is rarely abnormal; it is often seen in anxious individuals. One normal variant seen in a small proportion of adults is a low voltage background that looks suppressed (Figure **4-67**). However, a low voltage EEG would be abnormal in children and adolescents.

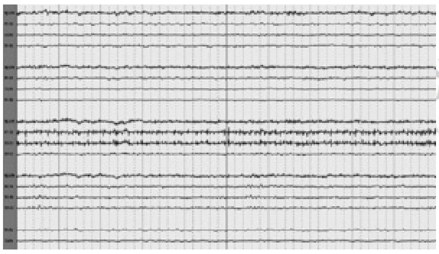

Figure 4-67:

Low voltage EEG in an anxious 50-year-old woman. There is muscle activity from the left temporalis muscle.

Generalized decreased cortical activity can occur with generalized cortical injury or transient dysfunction. Examples of generalized cortical injury include hypoxic-ischemic encephalopathy (HIE), or degenerative conditions such as advanced Huntington's disease; examples of transient dysfunction include drug-induced coma or postictal state after a generalized tonic-clonic seizure. Figure **4-68** shows marked suppression from pentobarbital coma. Figure **4-69** shows marked suppression and periodic complexes due to hypoxic encephalopathy.

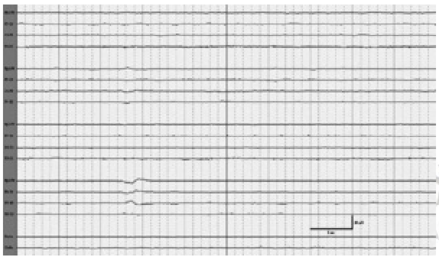

Figure 4-68:

Generalized attenuation of EEG activity due to pentobarbital coma. There is one brief burst of EEG activity in the right temporal region.

Figure 4-69:

Suppressed background with intermittent bursts. 76 year-old man with anoxic encephalopathy.

Excessive fluid or tissue overlying the cortex is more likely an explanation for focal rather than generalized attenuation. Examples include subdural hematoma or scalp edema. With subdural hematoma, the attenuation is most pronounced with bipolar recordings: there is cortical activity, but the conducting ability of the subdural fluid results in reduction of potential differences between electrodes and attenuates the recorded potential at the scalp. The same shunting of potential differences may occur with electrode gel smear on the scalp (often called salt bridge or electrical bridge).

Electrocerebral Inactivity (ECI)

Electrocerebral inactivity (ECI) or *isoelectric EEG* represents absence of electrocerebral activity. The definition of ECI is one with no cerebral activity over 2 µV. This is often called *electrocerebral silence* (ECS) and was so in the first edition of this text. In general ECI is a better term because this indicates perceived lack of electrical activity of the cerebral cortex. ECS uses the word *silence* which has an audio root, although the term *silent* sometimes means absence of motion. *Isoelectric* has been widely used but brain death recordings are never isoelectric (having no electrical charge or potential difference) and if they appeared that way then there is something wrong with the recording system.

The technical requirements of an ECI EEG are:

- Electrodes >10 cm apart
- Electrode impedance >100Ω, <10,000Ω;
- Hypothermia, drug intoxication, shock must be excluded;
- Record should be >30 min long at a sensitivity of 2µV/mm;
- Physiological monitoring must include EKG. Other physiological monitoring such as respiration and EMG is very helpful.

The background will look totally flat at a sensitivity of 7 µV/mm., except for artifact However, at a sensitivity of 2 µV/mm, the recording is never perfectly flat, and if it appears to be, either the gain needs to be increased or there is an electrical problem in the recording system. The residual activity more than 2 µV in the EEG should be proven to be of artifactual origin. In fact, artifacts are a major problem in interpretation. The artifact most commonly encountered is EKG artifact, which may take on a variable appearance at the scalp. Demonstrating perfect correlation with EKG channel is usually sufficient to prove the activity is not cerebral. The same is true for artifact due to respiration. However, a variety of rhythmic activities can be due to machine artifact, movement artifact, or muscle artifact. The EEG technologist may need to disconnect non-essential equipment, reposition the patient, pad respirator tubes with towels, or move electrodes.

ECI not necessarily equivalent to brain death. The criteria for determination of brain death include EEG as a confirmatory test if the other criteria are met (see Figure **4-70**). An ECI EEG indicates neocortical death and is supportive of the diagnosis of brain death in conjunction with the appropriate exam findings, if performed in accordance with accepted technical guidelines in the appropriate clinical situation.

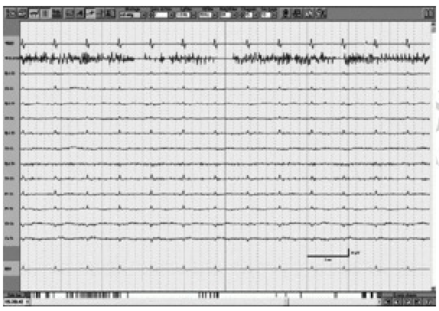

Figure 4-70:

Increase in EEG Activity

Focal Increase in EEG Activity

Focal increase in EEG activity is most often the result of a skull defect (Figure **4-71**). Since the skull filters fast activity, the presence of a defect is most likely to cause increased fast beta activity, as well as increased sharpness of less fast activity (sharpness represents a higher frequency component of that activity). Specific rhythms can become more prominent with skull defects in specific regions. For example, if the skull defect is over the central region, Mu activity may be exaggerated, and if the skull defect is over the temporal region, a third rhythm could become more prominent. The EEG activity over skull defects in these areas is often referred to as a *breach rhythm*. It is not clear that this should necessarily be considered an abnormality. It is rather an expected effect of a skull defect.

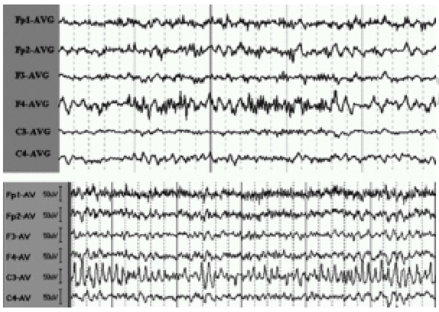

Figure 4-71:

Top segment shows increased beta activity over a right frontal skull defect. The bottom segment shows enhanced Mu and beta activity over a left central skull defect (breach rhythm).

Generalized Increase in EEG Activity

Excessive Fast Activity

Excessive fast activity is most commonly seen in patients receiving sedatives such as barbiturates or benzodiazepines. Chloral hydrate usually produces less excessive beta activity.

EMG activity from scalp muscles can appear as fast activity if its voltage is low, and when the high frequency filter is used. This can be differentiated from cerebral fast activity by asking the patient to relax and open the mouth.

Excessive beta activity should be interpreted as a minor abnormality, and the report should mention that a common cause is sedative medication. The neurophysiologists should not make this absolute determination without full knowledge of the patient, of course.

The patient recorded in Figure **4-72** has been treated with clonazepam and has some generalized slowing as well as excessive beta activity. Excess beta, by itself, is commented on in the interpretation, but is interpreted as a minor abnormality without other pathologic implications. Excess beta in one region usually means a skull defect and is interpreted as clearly abnormal.

Figure 4-72:

This patient has been treated with clonazepam and has some generalized slowing as well as excessive beta activity.

Excessive Slow Activity

This has been discussed above in the section Slow Abnormalities.

Periodic Patterns

Overview

Periodic discharges are repeated discharges with other intervening activity between discharges. They can be classified as lateralized or generalized/bilateral periodic discharges. Lateralized periodic discharges are often called *periodic lateralized epileptiform discharges* (PLEDs) even if the individual waveforms are not epileptiform. Generalized periodic discharges can be classified as short-interval and long-interval periodic discharges. Burst-suppression could also be considered a periodic pattern (see Table 4-14).

Table 4-14 Disorders with a Periodic Pattern	
Disorder	***Pattern***
Anoxia	Generalized or bisynchronous periodic discharges. Burst suppression pattern.
Herpes encephalitis	Periodic lateralized epileptiform discharges. Bihemispheric independent discharges are sometimes seen.
Creutzfeldt-Jakob disease (CJD)	Generalized periodic discharges are seen at some time during the course. Periodic discharges are not invariably seen, but typically develop within three months from onset of symptoms.
Subacute sclerosing pan-encephalitis (SSPE)	Generalized periodic discharges, of longer interval than CJD. Differentiated by other historical features.

Periodic Lateralized Epileptiform Discharges (PLEDs)

PLEDs are periodic discharges that are lateralized to one hemisphere (Figure **4-73**). This will include discharges that are focal, as well as others that affect one whole hemisphere. Some involvement of the other hemisphere is not unacceptable. Even though the term *PLEDs* excludes bihemispheric synchronous periodic discharges, PLEDs can occur independently in the two hemispheres, in which case they are termed biPLEDs. PLEDs are usually high in amplitude, at 100–300 μV. Lower voltage PLEDs can be difficult to identify in the background. The discharge may be simple or complex, with additional sharp and slow components superimposed on the waveform. In general, PLEDs are diagnosed only if they are present throughout the routine 20-minute EEG recording.

Figure 4-73:

Examples of PLEDs seen from the left hemisphere.There is a slight reflection of PLEDs in the right hemisphere, which is not unusual. The patient developed confusion, aphasia, and witnessed focal motor seizure activity of the right arm and face, 10 days after a left carotid endarterectomy and was found to have a hyperperfusion syndrome.

PLEDs are most often the result of acute structural lesion, such as stroke, acute infection, or rapidly growing brain tumor (for example, glioblastoma multiforme). However, PLEDs can also occur in patients with acute metabolic disturbance who also have a chronic structural lesion (especially in the setting of alcohol withdrawal). PLEDs can also occur in the setting of chronic epilepsy. Therefore, PLEDs are not specific for a particular diagnosis. PLEDs in the temporal or frontotemporal area can be a sign of herpes encephalitis.

The majority of patients with PLEDs have clinical seizures. However, there is a controversy over whether PLEDs themselves are ictal. The prevailing opinion is that PLEDs are not ictal, because more typical rhythmic ictal discharges are sometimes recorded in patients with PLEDs. However, there are patients with PLEDs who have myoclonic jerks synchronous with the discharges, suggesting that they may be ictal in some instances (see Figure **4-74**).

Figure 4-74:

Some features have been suggested that, if present, increase the odds that PLEDs are ictal. These features include:

- Fast rhythmic activity with the periodic complexes;
- Short interval between discharges; and
- Absence of background between discharges.

Generalized Periodic Discharges

These are bilateral discharges that may be prevalent in one part of the brain, usually anteriorly. They are often classified as short-interval or long-interval periodic discharges. Short-interval periodic discharges have a periodicity of 0.5–3 per second. They are more common and less specific than long-interval discharges. The main underlying

conditions include metabolic disturbances (for example, triphasic waves with hepatic encephalopathy), anoxic injury, toxic encephalopathy, Creutzfeld-Jakob disease, and non-convulsive status epilepticus. Clinical correlation is always required.

Creutzfeld-Jakob Disease

In Creutzfeld-Jakob disease (CJD), the majority of patients will develop periodic discharges in the first 3 months of the disease (Figure **4-75**). Figure **4-76** shows a second case of CJD—a 69-year-old with sporadic CJD.

Figure 4-75:

69-year-old patient with Creutzfeld-Jakob disease.

The top tracing showed only subtle periodic discharges that are easy to miss.

The bottom tracing obtained 2 weeks later showed very clear periodic discharges with a periodicity of 1.2 per second (Courtesy of Dr. Ivo Drury).

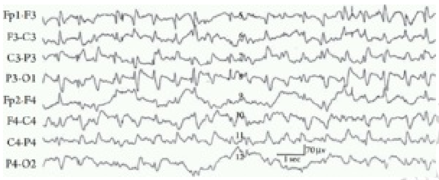

Figure 4-76:

Sporadic CJD in a 69-year-old. This recording was performed 3 days before death.

The periodic pattern is not always seen in the patients, as shown for the same patient on the earlier recording in Figure **4-77**. The periodic discharges evident later in the course are not obvious in this earlier recording. Stimuli can evoke the periodic discharges, as in the recording in Figure **4-78** from the same patient. Bursts are evoked by clapping.

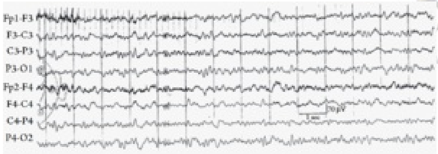

Figure 4-77:
Figure **4-76**.

The periodic discharges evident later in the course are not obvious in this earlier recording.

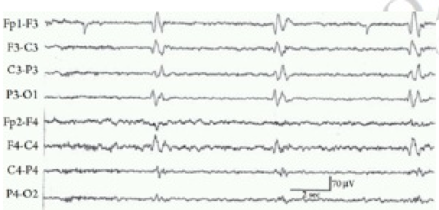

Figure 4-78:

Subacute Sclerosing Panencephalitis (SSPE)

Long-term periodic discharges have intervals of more than 4 seconds between discharges. They are more specific with respect to etiology, particularly when the clinical history is incorporated. Associated conditions include some toxic encephalopathies, such as with baclofen overdose and PCP or ketamine effect, anoxic injury, or subacute sclerosing panencephalitis (SSPE). When long-interval periodic discharges are seen in the setting of a dementing illness in a child who also has myoclonic jerks, they are fairly specific for SSPE (Figures **4-79** and **4-80**). In this condition, the interval between complexes becomes progressively shorter with disease progression.

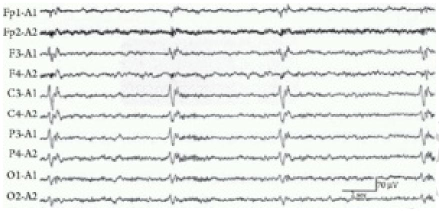

Figure 4-79:

Typical generalized periodic discharges in a child with SSPE. The interval between periodic complexes is 5–7 seconds (Courtesy of Dr. Ivo Drury).

Figure 4-80:

SSPE with periodic discharges.

Anoxic Encephalopathy

Anoxia can produce a variety of EEG features; among these are periodic discharges, which in this case are fairly synchronous between the hemispheres, although the slowing is markedly asynchronous.

Figure **4-81** is from a 9-year-old male who had anoxic encephalopathy due to choking on a ball.

Figure 4-81:

This is from a 9-year-old male who had anoxic encephalopathy due to choking on a ball.

Burst-suppression Pattern

The *burst-suppression pattern* is sometimes called the *suppression-burst pattern* since the duration of the suppression is usually greater than the duration of the burst. This pattern is seen mainly in patients with severe encephalopathy, although the pattern is not specific for any particular etiology. The most common causes are hypoxic-ischemic encephalopathy and medication-induced.

The burst-suppression pattern (Figure **4-82**) consists of epochs of relative flattening of the background (suppression), alternating with epochs of mixed frequency EEG activity (bursts). The bursts usually have a polymorphic appearance, but may contain high-voltage epileptiform activity, especially in some patients who are placed in barbiturate coma because of refractory status epilepticus.

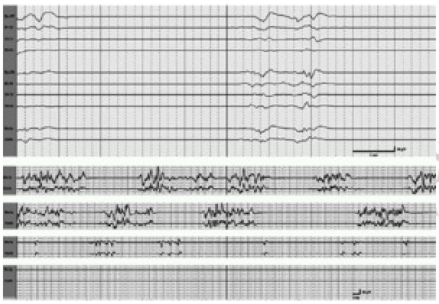

Figure 4-82:

The lower segments show compressed pages with 60 seconds per page. They show the progression with deepening level of coma.

Burst-suppression patterns can look similar, even though the clinical correlation is very different. In fact, this pattern resembles the discontinuous pattern of a normal 19-week conceptional age child, suggesting that the burst-suppression pattern may represent a primitive pattern of neuronal activity.

With drug-induced coma, the deeper the coma, the shorter the bursts and the longer the periods of suppression. Eventually complete suppression is reached.

When seen in association with hypoxic-ischemic encephalopathy, the burst-suppression pattern is indicative of a poor prognosis for neurological recovery. In fact, any periodic pattern is a poor prognostic indicator in this clinical setting (Figure **4-83**).

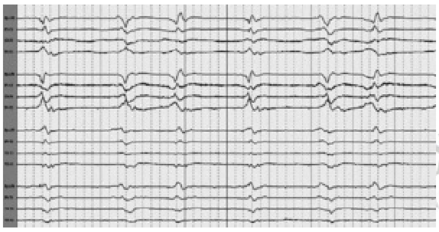

Figure 4-83:
The bursts are generalized but parasagittaly predominant. There is suppression of all frequencies between bursts. The suppression between bursts is variable but usually lasts around 1 second.

Coma and Electrocerebral Silence

Coma

Coma is a state of complete unresponsiveness. The differential diagnosis of coma is huge, but some of the most common causes are:

- Anoxia;
- Drug intoxication;
- Encephalitis;
- Stroke with resultant cerebral edema.

Alpha Coma

The EEG is dominated by alpha activity, which is non-reactive in a patient in coma due to anoxia. Alpha coma (Figure **4-84**) is generally considered to indicate poor prognosis, depending on etiology of the coma and concurrent medications, which can affect EEG background.

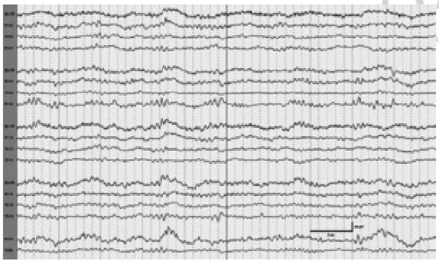

Figure 4-84:

The EEG is dominated by alpha activity, which is non-reactive in a patient in coma due to anoxia.

Spindle coma

Spindle coma (Figure **4-85**) was initially described as an indicator of poor prognosis, but subsequently the appearance of spindles has been seen in patients who ultimately had good outcomes. If the spindles are seen with other sleep rhythms, including vertex waves, then the spindles are supportive of a favorable prognosis. The frontal spindles of encephalopathy appear different from sleep spindles, so these should be considered different processes.

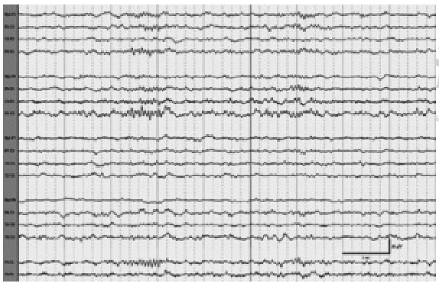

Figure 4-85:

The EEG in a comatose patient shows spindle-like activity.

Electrocerebral Inactivity (ECI)

ECI was discussed earlier in this chapter as an extreme example of an amplitude abnormality. ECI means that there is no definite electrocerebral activity recorded with scalp electrodes. ECS is supportive of the diagnosis of brain death, which is discussed further below.

Brain Death

Brain death (BD) criteria have been published for adults and children, although there are no agreed-upon criteria for newborns.

Determination of brain death is performed when a patient with intracranial catastrophe has complete lack of response on examination, despite the absence of sedatives or neuromuscular blocking agents.

Guidelines for Determination of Brain Death in Adults

The Medical Consultants on the Diagnosis of Death to the President's Commission for the Study of Ethical Problems in Medicine and Biomedical and Behavioral Research published guidelines for the determination of brain death in 1981. Guidelines were also published by the American Academy of Neurology in 1995 (AAN, 1995). An update was subsequently published in 2010 (Wijdicks et al., 2010). Details of the criteria for brain death are not within the scope of this text so the reader is referred to especially the Wijdicks reference for guidance.

Patients being evaluated for BD will frequently be hypothermic and hypotensive; therefore, maintenance using warming blankets and pressors is often required. Evidence against neuromuscular blockade can be the presence of tendon reflexes, the presence of primitive responses to nociceptive stimulation, or the response of the muscle to electrical stimulation of motor nerves.

The original guidelines for determination of BD indicate that there should be a period of observation, with documentation of examinations for BD before and after this period (see Table 4-15 for a summary of the criteria, but this is not comprehensive).

Table 4-15 Procedures for Determination of Brain Death in Adults

Criterion	***Requirement to Meet Criterion***
Steps for determination of brain death	Establish irreversible and proximate cause of coma. Achieve normal core temperature Achieve normal systolic blood pressure Perform a neurologic exam for brain death.
Clinical examination for brain death	*No responsiveness*: Including no eye opening or movement to noxious stimuli. *Absence of brainstem reflexes*: Pupil responses, oculocephalics, oculovestibular reflex, corneal reflex, facial movement ot noxious stimuli, pharyngeal and tracheal reflexeses. *Apnea*: Absence of breathing drive.
Ancillary tests	Use of ancillary tests is indicated especially if there is uncertainty about reliability of certain parts of the examination or when apnea testing cannot be performed. Depending on protocols, an ancillary test can reduce the period of observation before determining brain death. Preferred antillary tests include EEG, radionucleotide flow study, and angiography.

Extracted in part from Wijdicks et al., (2010)

Details of the determination of brain death are best outlined as published by Wijdicks et al. (2010). This document is available from multiple sources including online. This publications even includes a helpful checklist.

BD should usually be established by clinical findings alone, if possible. Some patients with no clinical evidence of cerebral or brainstem activity may have evidence of EEG activity but otherwise fulfill the clinical criteria for BD. The literature is not clear on what to do in this situation.

Guidelines for Determination of Brain Death in Children

The 1981 President's Commission did not make specific recommendations for the determination of BD in children. The only specific comment recommended "caution in children under the age of five years." The Task Force for Brain Death in Children (1987) subsequently provided recommendations that are increasingly used. In 2011, a successor to this task force published revised guidelines (Nakagawa et al., 2011). These recommendations are too extensive to be repeated here and are not within the scope of this book, so the reader is referred to these references for details. Suffice it to say that the recommendations for children, especially the very young, are more stringent than for adults. But the essentials of EEG performance are similar.

EEG for Brain Death

EEG is one of the recognized confirmatory tests for brain death in children and adults. However, the protocol for the test differs from routine hospital or even intensive care unit EEG (see Table 4-16).

Table 4-16 Technical Standards for Brain Death EEGs	
Parameter	***Features***
Number of electrodes	Minimum of 8 covering all brain regions, usually a reduced version of the 10-20 electrode placement system. A full set of electrodes is preferred. Usually Fp1, Fp2, C3, C4, O1, O2, T3, T4, as a minimum
Inter-electrode distances	At least 10 cm, which is greater than normal distances. This allows for better detection of low-amplitude EEG activity.
Inter-electrode impedances	No greater than 10 kohm but no less than 100 ohms. Too low an impedance suggests electrode paste smear. Amplitude of the recorded activity will be excessively low if impedance is low.
Sensitivity	2 μV/mm during most of the recording
Low-frequency filter (LFF)	not above 1 Hz
High-frequency filter (HFF)	not below 30 Hz
Physiological monitoring	EKG is routinely monitored since at high sensitivities EKG contamination of the EEG is common. Chest wall motion if needed to determine if slow activity is respiratory.
Duration	At least 30 min of relatively artifact-free recording.
Reactivity	Test reactivity of the EEG to auditory, visual, and tactile stimuli.
Integrity	Test the integrity of the system by touching the electrodes to evoke a high-amplitude artifact. This ensures that a flat background is not due to technical factors.
Telephone transmission EEG	Telephone transmission EEGs cannot be used to support the diagnosis of brain death.
Technologist	Recording should be made by a qualified technologist.

Brain Death Studies in Adults

BD studies should be performed in the period of observation between two extensive neurologic examinations. All of the above recommendations should be followed. All physiologic parameters set forth by the President's Commission should be followed regarding temperature, blood pressure, and absence of sedative and neuromuscular blockers (see Figure **4-86**).

Figure 4-86:

Sensitivity = 2 μV/mm

Brain Death Studies in Children

BD studies in children are performed in the same manner as BD studies in adults. More physiologic monitoring is often required in children's studies, however. Because of small body size, respiratory movement artifact is relatively greater, and a chest-wall sensor is desirable. An EKG channel is important for adult studies but is even more important for BD studies in children; at high sensitivities, EKG artifact can be the predominant potential in the record.

EEG after Therapeutic Hypothermia

Years of study on prognostic significance of EEG, clinical findings, and biomarkers have been complicated by the increasingly widespread use of therapeutic hypothermia. The prognostic implications after hypothermia do not necessarily still apply. EEG is seldom performed during the cooled phase, but is done after rewarming; a richer background and reactivity indicates a better prognosis (Kawai et al., 2011).

Continuous EEG recording in patients during and after therapeutic hypothermia showed that poor outcome was predicted by seizures, non-reactive background, and epileptiform discharges (Crepeau et al., 2013). In this same study, treatment of the seizures did not improve outcome.

Abnormal Epileptiform EEG

Role and Diagnosis and Management

The EEG helps to provide support for the clinical diagnosis of epilepsy but should generally not be the basis for that diagnosis in the absence of clinical information.

The EEG has a role in all of the following:

- Help diagnose epilepsy;
- Help diagnose status epilepticus;
- Help classify the epilepsy and epileptic syndrome;
- Help localize the epileptogenic zone;
- Help predict seizure recurrence after a first unprovoked seizure or after anti-epileptic drug withdrawal;
- Help follow response to therapy in one specific form of epilepsy, idiopathic generalized epilepsy with absence seizures. In this situation, improvement in seizure control is reflected with decreased epileptiform discharges on EEG.
- Infrequently, provide evidence for the etiology of epilepsy. The EEG is generally non-specific with respect to etiology.

EEG Analysis in Patients with Suspected Epilepsy

When potentials are found that are suspicious for interictal or ictal activity, there is a sequence of questions to be considered in analysis:

- Is the discharge cerebral or artifactual?
- If the discharge is cerebral—is the discharge normal or abnormal?
- If the discharge is abnormal—is the discharge specific for epilepsy, i.e., epileptiform?
- If the discharge is epileptiform—is the discharge focal or generalized?
- If the discharge is focal—what is the field of the discharge?

This sequence of steps can seem simple, but when faced especially with a difficult interpretation, consideration of basic analysis can be helpful. For example, multifocal sharp transients in a premature infant may look epileptiform but be normal for the conceptional age. Or, an apparent generalized seizure in an older adult may be associated with focal sharp waves, suggesting secondary generalization of a focal epilepsy due to a structural lesion.

Discharges Associated with Epilepsy

In the routine 20- to 30-minute EEG, it is most likely that only interictal abnormalities will be seen. These are the abnormalities most often sought in routine EEGs for epilepsy. Interictal abnormalities that are specific for epilepsy are termed *epileptiform*. It is generally suggested that the term *epileptiform* be reserved for interictal discharges associated with epilepsy, while ictal EEG findings are termed *seizure patterns* or *ictal patterns* (see Table 4-17). Seizure patterns are only infrequently seen in the routine EEG. One notable exception to that are ictal discharges associated with absence seizures. Absence seizures are almost reliably precipitated with hyperventilation in the untreated child with childhood absence epilepsy.

Table 4-17 Discharges Associated with Epilepsy

Discharge	*Clinical Association*
Focal spikes and sharp waves	Suggest partial epilepsy with a focus at the locus of the spike, especially if localization is consistent and persistent.
3 Hz generalized spike and wave	Suggest generalized epilepsy, most commonly typical absence epilepsy.
Slow spike and wave	Generalizes spike-wave discharge of 2.5 Hz or less suggests symptomatic generalized epilepsy, especially Lennox-Gastaut syndrome.
Fast spike and wave	Discharges faster than 4 Hz suggest especially juvenile myoclonic epilepsy.
Focal ictal discharge	Focal repetitive discharges with changing frequency, usually decreasing but occasionally fluctuating or even increasing.
TIRDA (temporal intermittent rhythmic delta activity	TIRDA is fairly specific for partial epilepsy of temporal lobe origin but is not ictal. However, the strong correlation between this pattern and epilepsy deserves mention in the interpretation.

Focal spike or sharp waves without clinical seizures is occasionally seen when an EEG is performed for a non-epileptiform indication such as behavioral disorder, developmental delay, or perhaps even an inappropriate indication (see Table 4-18). It is possible that the patient may have seizures that are not noticed by observers, so evaluation in the epilepsy monitoring unit (EMU) may be necessary. However, we should avoid placing individuals on AEDs unless there is a clear indication, so we treat the patient, not the EEG. Report of such an EEG might read something like:

> Abnormal study because of epileptiform activity arising from the right temporal lobe. In the appropriate clinical situation, this would be supportive of a partial seizure disorder, however, the presence of this pattern does not mean that the patient is having seizures.

Table 4-18 Spikes and Sharp Waves Not Associated with Epilepsy	
Spikes and sharp waves	***Examples***
Normal	Vertex waves
	Occipital lambda waves
	14 and 6 Hz positive spikes
	Wicket spikes
	Benign epileptiform transients of sleep (BETS)
	Positive occipital sharp transients of sleep (POSTS)
	6-per-second (phantom) spike and wave
Abnormal	Periodic lateralized epileptiform discharges (PLEDs)
	Breach rhythm
	Focal spike or sharp wave without clinical seizures.

Epileptiform Discharges

These include spikes and sharp waves and combinations of these with slow waves (see Chapter 3). By definition, spikes are shorter than 70 milliseconds, whereas sharp waves are 70–200 milliseconds in duration. Other epileptiform discharges include spike-and-wave complexes, slow spike-and-wave complexes, sharp-and-slow-wave complexes, multiple-spike complexes (or polyspike complexes), multiple-spike-and-slow-wave complexes (or polyspike-and-slow-wave complexes), multiple-sharp-wave complexes, and multiple-sharp-and-slow-wave complexes.

Many EEG waves have a sharp appearance, but they are only called spikes or sharp waves if they satisfy a number of features, including a relatively high voltage compared to the background, an asymmetric temporal appearance of the wave typically with a shorter first half and a longer and higher voltage second half, a biphasic or polyphasic morphology, and after-going slow wave. Spikes and sharp waves should be differentiated from the background and not just a higher voltage or sharper, but otherwise similar to surrounding rhythmic activity. The great majority of sharp waves and spikes are surface negative. They generally have a field that includes more than one electrode. They should be different from what is expected as physiologic activity in the particular field and state of alertness. Not all the above features have to be present, however, the more features present, the more confident one can be of the "epileptiform nature." (see Figure **4-87**).

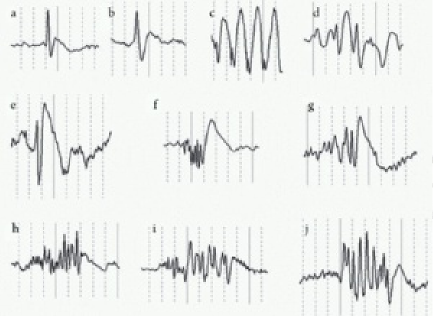

Figure 4-87:

a- spike; b- sharp wave; c- spike-and-wave complexes; d- sharp-and-slow-wave complexes; e- slow-spike-and-slow-wave complex; f- polyspike-and-wave complex; g- multiple-sharp-and-slow-wave complex; h- polyspike complex; i & j- multiple sharp wave complexes.

Even though spikes and sharp waves usually have after-going slow waves, the term *spike-and-wave complex* is usually reserved for the situation where the slow wave is very prominent, often higher in voltage than the spike.

Ictal versus Interictal Epileptiform Discharges

Ictal discharges are usually not merely repetition of interictal discharges and will generally have an appearance different from multiple interictal discharges. One exception to this fairly clear differentiation between ictal and interictal discharges is generalized absence seizures. The distinction between interictal and ictal discharges is not always clear-cut. For example, in patients with generalized absence seizures it has been demonstrated that a subtle alteration of responsiveness occurs even with a single spike-and-wave discharge, if responsiveness is tested with sensitive tools. On the other hand, generalized spike-and-wave discharges that are shorter than 3 seconds are generally not appreciated by family members, particularly in the absence of motor accompaniments. Therefore, for practical purposes, one could state that bursts of generalized spike-and-wave discharges are ictal if they last more than 3 seconds, or if they are associated with clear clinical changes.

Another pattern that can be ictal or “interictal” is that of paroxysmal fast activity noted in patients with symptomatic generalized epilepsy, particularly those with Lennox-Gastaut syndrome. In these patients, the paroxysmal fast activity (or generalized polyspike activity) can be associated with generalized tonic seizures or could be totally asymptomatic. Occasionally, such discharges cause arousal as their only clinical manifestation.

Compare Figure **4-88** with the ictal discharge from the same patient in Figure **4-89**.

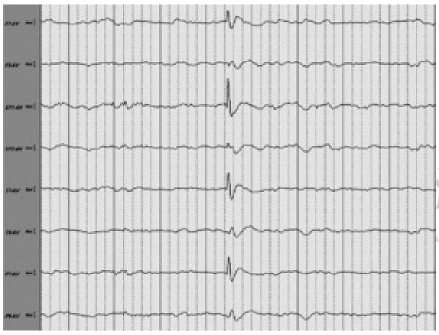

Figure 4-88:

Left temporal sharp wave in a 35-year-old woman with epilepsy and left hippocampal sclerosis. Compare with the figure below of ictal discharge in the same patient.

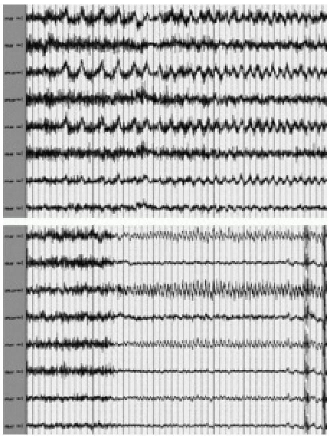

Figure 4-89:

Left temporal ictal discharge in the same patient as Figure **4-88**.

Types of Epilepsy Associated with Specific EEG Patterns

Focal Spikes and Sharp Waves

Focal spikes or sharp waves generally suggest focal or partial epilepsy, particularly if there is a single and consistent localization (Figure **4-90**). For example, consistent right anterior temporal spikes or sharp waves suggest right anterior-mesial temporal lobe epilepsy, and consistent left occipital spikes suggest left occipital lobe epilepsy.

Figure 4-90:

Right temporal sharp wave in a patient with right temporal lobe epilepsy.

Two independent spike or sharp wave foci still suggest partial epilepsy in most instances. However, if the discharges are frontal or central, they can be consistent with generalized epilepsy. In generalized epilepsy, “fragments” of generalized epileptiform discharges could be noted, particularly in sleep, in the frontal or central regions (see Figures **4-91** and **4-92**). As a rule, patients with generalized epilepsy will have generalized epileptiform discharges as well as these “fragments.”

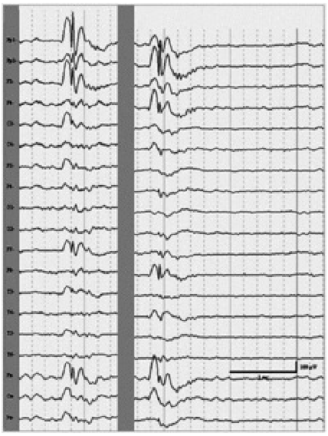

Figure 4-91:

Shifting left and right frontal epileptiform discharges in a patient with generalized epilepsy. These are termed fragments of generalized discharges.

Figure 4-92:

Shifting asymmetries in an 18-year-old woman with idiopathic generalized epilepsy.

When there are two or more independent foci, the localization of the epileptogenic focus becomes less certain. Many patients will still have a single ictal focus, i.e., seizures may start in a single location even though interictal epileptiform activity is bilateral or even multifocal (Figure **4-93**). However, patients with independent foci are more likely to have independent seizure onsets than those with single consistent foci (Figure **4-94**).

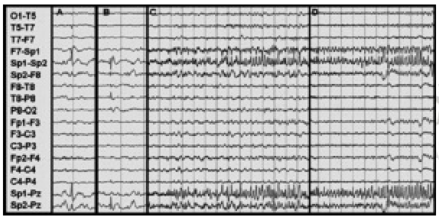

Figure 4-93:

Independent left and right temporal sharp waves (A & B) but consistent left temporal seizure onsets (C&D) in a 46-year-old man with intractable complex partial seizures since age 5 and left hippocampal sclerosis.

Figure 4-94:

Independent left and right temporal sharp waves in a 34-year-old woman with intractable complex partial seizures proven to start independently in the right and left temporal regions.

3Hz Generalized Spike-and-Wave Discharges (range 2.5–4Hz)

These discharges suggest generalized epilepsy. If they are noted in rhythmic, regular, synchronous, and symmetrical trains, then they are strongly suggestive of the presence of typical absence seizures. Typical absence seizures generally correspond to normal intelligence and normal neurological status. As mentioned above, duration of 3 seconds or more is usually needed for seizures to be noticed by observers. Occasionally, however, the presence of motor manifestations in these seizures can make shorter discharges associated with clinically detectable seizures. In sleep, generalized spike-and-wave discharges tend to become irregular and longer in duration. In addition, with sleep there is frequently a change in morphology to generalized polyspike-and-wave discharges. Therefore, the appearance of these discharges in sleep cannot predict the appearance in waking (see Figures **4-95** and **4-96**).

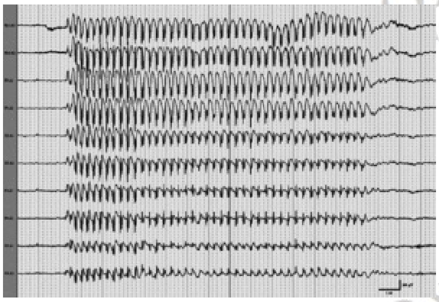

Figure 4-95:

Absence seizure in 9-year-old girl with spells of staring and unresponsiveness for one year. She averaged 2 to 3 attacks per day, lasting seconds to 1 minute.

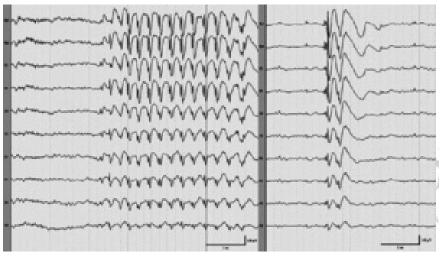

Figure 4-96:

19-year-old with absence seizures since age 13. Spike-and-wave discharges were regular in waking but become irregular polyspike-and-wave discharges in sleep.

Slow Spike-and-Wave Discharges

A frequency of generalized spike-and-wave discharges below 2.5 Hz results in the term *slow spike-and-wave* or *atypical spike-and-wave* (Figure **4-97**). This should be based on the frequency of discharges in waking and not in sleep. Slow spike-and-wave discharges are suggestive of symptomatic generalized epilepsy such as Lennox-Gastaut syndrome. They are associated with brain damage, and clinically correlated with atypical absence seizures. Atypical absence seizures are clinically very similar to typical absence seizures except that they may have a lesser alteration of consciousness or responsiveness with them, may have a slower onset and a more gradual termination, as well as more prominent motor features. Slow spike-and-wave discharges are more often asymmetrical and may be associated with focal epileptiform and non-epileptiform abnormalities.

Figure 4-97:

Fast Spike-and-Wave Discharges

Discharges that are faster than 4 Hz are called *fast spike-and-wave discharges* (Figure **4-98**). These typically range from 4 to 7 Hz in frequency. They are seen in association with juvenile myoclonic epilepsy, but also with other generalized idiopathic epilepsies, even in the absence of myoclonic seizures. Fast spike-and-wave discharges tend to be irregular and tend to occur in clusters. These clusters can be associated with myoclonic seizures or could be subclinical/interictal. In juvenile myoclonic epilepsy, they are most likely to be recorded after arousal, particularly following sleep deprivation.

Figure 4-98:

The frequency of spike-and-wave discharges here is approximately 5 Hz.

Focal Ictal Discharges

Ictal discharges in association with partial epilepsy typically involve rhythmic activity that evolves in frequency, morphology, voltage, and distribution, during its course. Although it is most common for discharges to gradually decrease in frequency between their onset and their termination, it is not at all uncommon for frequency to fluctuate, increasing and then decreasing. However, toward the end of the seizure there is almost always a reduction in frequency prior to termination. The end of the seizure is sometimes clear-cut and at other times not. The postictal slow activity can occasionally be difficult to distinguish from the rhythmic ictal activity towards the end of the seizure, which can also be in the delta range.

Focal ictal discharges (Figures **4-99** and **4-100**) may start with voltage attenuation. If this attenuation is focal, it has a localizing value. At other times, the attenuation is diffuse and less useful. The presence of high-frequency beta range activity at seizure onset suggests neocortical involvement.

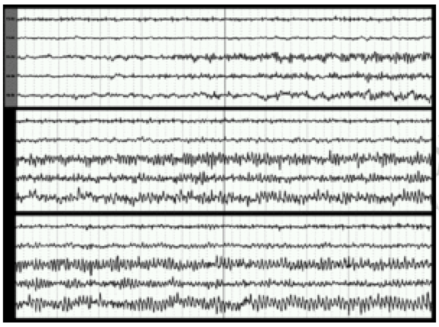

Figure 4-99:

Three consecutive 10-second EEG segments showing onset and initial evolution of a right occipital ictal discharge. The evolution included increase in voltage, decrease in frequency, and widening of the field.

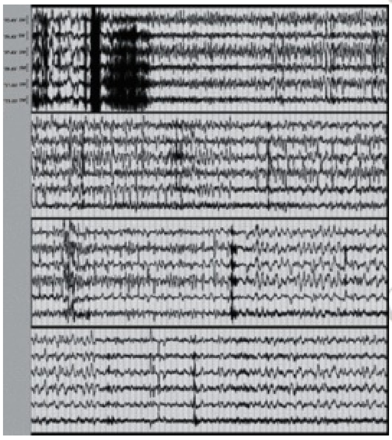

Figure 4-100:

Left fronto-temporal ictal discharge displayed on compressed EEG (60-second segments), showing evolution with increasing amplitude, decreasing frequency, widening field, and then abrupt termination (arrow). Postictal slow activity can be seen at F7 and T7.

Hippocampal seizures will typically start in the theta range, and infrequently in the alpha range. Seizure onset in the delta range may suggest that the center of seizure activity is at some distance from where the delta activity is recorded. In the case of temporal lobe epilepsy, a theta discharge in the anterior-mesial temporal region should be seen within 30 seconds of ictal onset. If not, the temporal localization is less than certain.

TIRDA (Temporal Intermittent Rhythmic Delta Activity)

This pattern is not ictal in nature, but it seems to be quite specific for temporal lobe epilepsy. It is different from intermittent irregular delta activity, which is very non-specific in nature. Although TIRDA is not yet considered epileptiform in most textbooks, the EEG interpreter may comment that this pattern is strongly associated with potential epileptogenicity (Figure **4-101**).

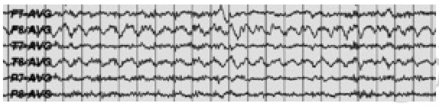

Figure 4-101:

Right temporal rhythmic delta activity in a patient with right temporal lobe epilepsy

Patterns of EEG Activity in Certain Forms of Epilepsy

Temporal Lobe Epilepsy

Temporal lobe epilepsy may be associated with a normal first EEG in about 50% of instances. With repeated recordings, approximately 90% of patients will demonstrate epileptiform abnormalities. There will be approximately 10% of patients who will always have a normal EEG between seizures. Irregular delta activity may be the only EEG abnormality in some patients with temporal lobe epilepsy. This is typically recorded from the anterior midtemporal region. TIRDA (see above) is strongly suggestive of temporal potential epileptogenicity. Spikes-and-sharp waves are typically activated in drowsiness and sleep and also increase after the occurrence of seizures, particularly after the occurrence of secondarily generalized tonic-clonic seizures. As a result, in patients whose EEGs are repeatedly normal, one should try to obtain an EEG shortly after a seizure. This can help with the appearance of postictal slow activity as well as activation of epileptiform discharges.

In mesial temporal lobe epilepsy, spikes-and-sharp waves will typically have a higher voltage anteriorly at F7 or F8. If T1/T2 electrodes are used, they may have the highest field or the highest amplitude. If sphenoidal electrodes are used, they often have the highest amplitude. There are some patients who have discharges only recorded from the sphenoidal electrodes (Figure **4-102**).

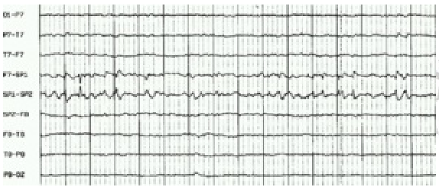

Figure 4-102:

The focal epileptiform and slow activity is limited to the left sphenoidal electrode in a patient with left temporal lobe epilepsy.

Approximately one-third of patients with temporal lobe epilepsy have independent bitemporal discharges, particularly in sleep. It is very common that during sleep the field of epileptiform discharges widens and mirror foci appear. If unilateral focal spike activity is seen in waking and an independent contralateral discharge is noted only in sleep, the waking activity is the most reliable for localization of the seizure focus. In REM sleep there is also a narrowing of the field and attenuation of mirror foci. Therefore, in patients with bilateral independent epileptiform discharges, those interictal epileptiform discharges recorded in waking or REM sleep are the most reliable for localization. Most patients with bitemporal independent epileptiform discharges will still have unilateral seizure onsets, but they have a higher chance of independent bitemporal seizure onsets than patients with unilateral epileptiform discharges.

If ictal discharges are unilateral, the side with the highest frequency of epileptiform discharges is typically the side of seizure onset. A small proportion of patients may have generalized spike-and-wave discharges. This is not unexpected, as a high proportion of patients may have a family history of epilepsy as well as a history of febrile convulsions early in life. The generalized spike-and-wave discharges are suspected to be an inherited EEG trait.

Temporal simple partial seizures (Figure **4-103**) are most often not associated with EEG changes. If they are, the EEG changes tend to be subtle and quite focal.

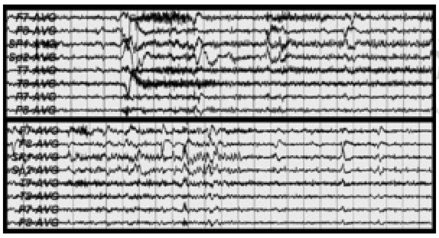

Figure 4-103:

The ictal discharge is very focal, involving Sp1 and to a lesser extent Sp2. The subtle ictal discharge could have been missed without the termination

Complex partial seizures, on the other hand, are almost always associated with a clear-cut ictal discharge. In mesial temporal lobe epilepsy, the ictal discharge is in the theta range at onset or shortly after onset (Figure **4-104**). If sphenoidal electrodes are used, at least 5 Hz rhythmic activity noted in one sphenoidal electrode within 30 seconds of seizure onset is strongly supportive of lateralization and localization. In secondarily generalized tonic-clonic seizures of temporal lobe origin, the same EEG changes are seen early on, but the ictal discharge becomes generalized with extensive and diffuse muscle artifact masking the EEG.

Figure 4-104:

The ictal onset is with approximately 6–7 Hz rhythmic activity, predominant at Sp2 and F8.

It may be difficult to distinguish neocortical from mesial temporal lobe epilepsy. If sphenoidal electrodes are used, temporal lobe ictal activity not represented in the sphenoidal electrode may favor a lateral temporal onset. With a neocortical origin, there may be more rapid spread of the ictal discharge to extratemporal regions, and the discharge is more often bilateral from onset (see Figure **4-105**). A high-frequency beta range activity at onset favors a neocortical localization close to the recording electrode. However, a temporal beta frequency discharge could represent an extratemporal origin.

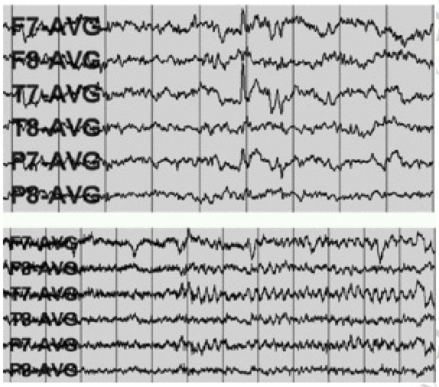

Figure 4-105:

Posterior Temporal Lobe Epilepsy

In posterior temporal lobe epilepsy, the interictal epileptiform discharges tend to have predominance in the posterior or midtemporal electrodes, and not in the anterior temporal region or the sphenoidal electrodes (see Figures **4-106a**, **4-106b**, and **4-107**). The field may involve the parietal or occipital electrodes.

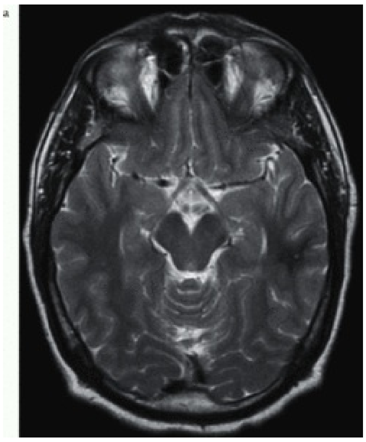

Figure 4-106a:

T2 - MRI brain slice showing lesion in the left posterior temporal region.

Figure 4-106b:

EEG samples showing the discharge on both sphenoidal and scalp leads.

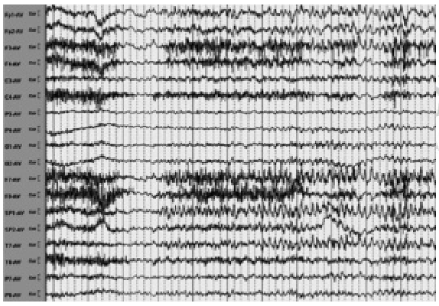

Figure 4-107:

Interictal epileptiform discharges in this patient included both anterior-inferomesial temporal sharp waves (Sp1 and F7) and posterior-mid temporal spikes (P7 and T7).

Ictal discharge onset also tends to predominate in the posterior temporal region and not involve the sphenoidal electrodes. However, interictal epileptiform activity and ictal onset may be falsely localized. Some patients with posterior temporal lobe epilepsy may have only anterior-inferomesial temporal sharp waves, or both posterior temporal and anterior-inferomesial temporal epileptiform activity. In these patients, ictal discharges may also appear to be anterior-mesial temporal. In patients with posterior temporal lesions, such false localization historically resulted in leaving the lesion and resecting the anterior temporal and hippocampal regions, with poor surgical results.

The ictal onset appears to be typical of anterior- inferomesial temporal lobe epilepsy. The patient in Figure **4-106** became seizure-free with lesionectomy, without removal of the anterior and mesial temporal structures.

Frontal Lobe Epilepsy

The frontal lobe is the largest lobe and has surfaces that are invisible or relatively invisible to EEG. Orbitofrontal onset seizures and mesial frontal onset seizures may have essentially no surface EEG manifestations. In orbitofrontal epilepsy, epileptiform discharges may be recorded from the frontopolar electrodes or from supraorbital electrodes (Figure **4-108**). In mesial frontal lobe epilepsy, the midline electrodes or parasagittal electrodes may record epileptiform discharges. On occasion, these discharges can be confused with vertex waves in sleep (Figure **4-109**). Their occurrence in waking can help resolve this confusion. Anterior lateral frontal, dorsolateral frontal, and central foci can be associated with focal spike discharges in these regions (Figure **4-110**).

Figure 4-108:

Right frontal spike-and-wave discharges in a patient with a right frontal convexity epileptogenic focus. There is reversal of polarity of discharges at F4.

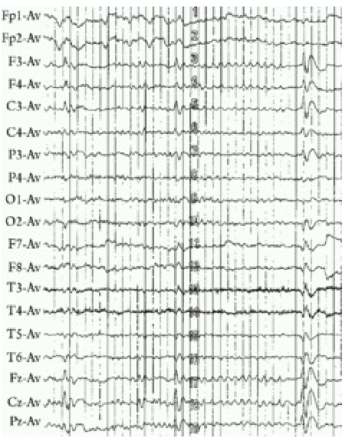

Figure 4-109:

The sharp waves are predominant at Cz. These are not vertex waves because the patient is awake.

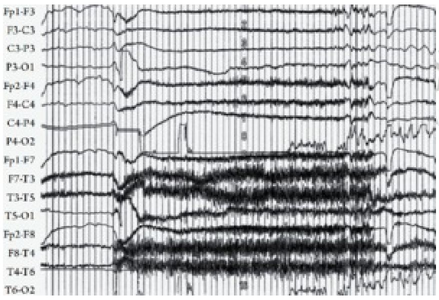

Figure 4-110:

The ictal discharge could be easily missed. Definite EEG changes are noted toward the end of the discharge (indicated by arrow).

It is not uncommon for secondary bilateral synchrony to occur in frontal epilepsy. This is to be distinguished from primary bilateral synchrony seen in generalized epilepsy. Secondary bilateral synchrony is where focal spikes or sharp waves lead to bilateral synchronous discharges. This can be suspected when bilateral discharges have a consistent asymmetry or a consistent lead on one side, when some focal discharges are seen only one side, or when a consistent focal slow abnormality is seen (see Figures **4-111a**, **4-111b**, **4-111c**).

Figure 4-111:

There is a lead on the right in the discharge (a), a consistent asymmetry is noted with right predominance (a and b), and right frontal slow activity is noted intermittently (c).

Frontal lobe seizures have a tendency to become rapidly generalized. Seizure spread is at times so fast that a focal onset could be hard to distinguish. The presence of high-frequency focal fast activity at seizure onset suggests good localization of the seizure focus to the region of fast activity (Figure **4-112**).

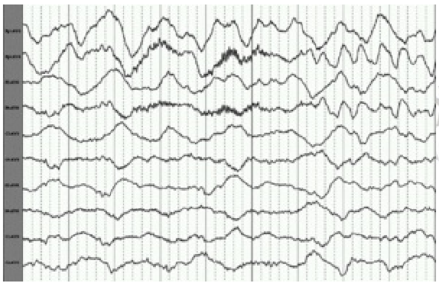

Figure 4-112:

The ictal activity is in the beta range at onset. The ictal discharge was associated with left arm twitching.

Occipital and Parietal Lobe Epilepsies

Occipital lobe epilepsy can be associated with focal spike or spike-and-wave discharges in the occipital region (Figure **4-113**). It is not uncommon for discharges to be bilateral, since volume conduction occurs frequently at the occipital poles (as it does at the frontal poles). Occipital lobe seizures can develop focally or regionally, or can spread to frontal or temporal lobe regions. Seizures starting above the calcarine fissure tend to spread to the frontal lobe, whereas seizures starting below the calcarine fissure tend to spread to the temporal lobe. Occipital lobe seizures that remain regional have a tendency to develop very slowly, starting with beta range activity that gradually evolves to alpha range and then theta range and then delta range, over several minutes. The progression of the ictal discharge can be so slow that the seizure may not be appreciated until the EEG has changed quite drastically.

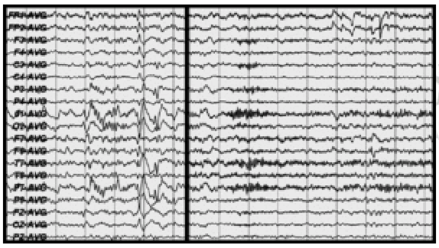

Figure 4-113:

Patient with a left posterior quadrant (predominantly occipito-temporal) seizure focus

The EEG is often misleading in parietal lobe epilepsy. Only some patients have focal parietal interictal epileptiform abnormalities and ictal discharges. Many patients have abnormalities in the temporal or frontal regions, resulting in false localization.

Benign Rolandic Epilepsy or Benign Epilepsy with Centrotemporal Spikes (BECTS)

In this condition, epileptiform discharges have a typical appearance with broad blunt sharp waves (Figure **4-114**). The classical field is with negativity in the central and mid-temporal regions and positivity bifrontally. However, there are very frequent variants to this field distribution. The discharges are commonly more posterior, involving posterior temporal and parietal regions. Some patients may have coexistent occipital lobe discharges. Marked activation of epileptiform activity in sleep is typical. It is quite common for discharges to be recorded independently on the two sides in sleep. Awake recordings may completely miss the epileptiform activity, hence sleep is essential. Ictal recordings are very rare in this condition. In fact, seizures are often a rare occurrence despite the high incidence of interictal epileptiform discharges.

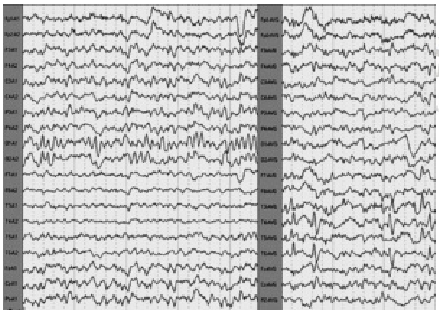

Figure 4-114:

The EEG was normal in waking (left), but very frequent independent left and right mid-posterior temporal sharp waves were activated in sleep, with associated frontal positivity (arrow).

In patients with benign rolandic epilepsy, there is an increased incidence of generalized spike-and-wave discharges. In fact, in some patients, there may even be typical absence seizures. In such instances, it may be somewhat difficult to identify the specific clinical syndrome, as to whether it is benign rolandic epilepsy or childhood absence epilepsy. (Figure **4-115**)

Figure 4-115:

The first segment to the left shows typical discharges of benign rolandic epilepsy, with bifrontal positivity (arrowhead). A generalized epileptiform discharge is seen to the right in the same patient.

Benign Epilepsy with Occipital Paroxysms

In benign epilepsy with occipital paroxysms, high voltage spike-and-wave discharges or sharp waves are recorded over the occipital and posterior temporal regions unilaterally or bilaterally, synchronously or independently (Figure **4-116**). They tend to occur in repetitive trains at times. They are typically blocked by eye opening and enhanced by eye closure. They may coexist with centrotemporal or generalized spike-and-wave discharges.

Figure 4-116:

Eye opening blocked the left occipital discharges, while eye closure enhanced them.

Signs associated with Epileptiform Discharges

The clinical signs associated with epileptiform discharges span a wide range (Table 4-19). Some of the most common are discussed here:

Table 4-19 Clinical Correlates to Epileptiform Discharges

Type of Discharge	***Pattern***	***Seizure types***
Interictal discharges	3-per-second spike-wave pattern	Absence seizuresGeneralized tonic-clonic seizures
	Fast spike-wave complex	Generalized tonic-clonic seizures
	Slow spike-wave complex	Lennox-Gastaut syndrome
	Hypsarrhythmia	Infantile spasms
Focal discharge	Temporal lobe focus	Complex partial seizures
	Frontal lobe focus	Complex partial seizures and simple partial seizures.
	Parietal lobe focus	Simple partial seizures especially with sensory symptoms
	Occipital lobe focus	Simple partial seizures, especially with visual symptoms

Focal motor activity: Simple partial seizures can present with focal jerking, especially of face and/or arm. This is simple positive motor phenomena. Adversive maneuvering is less common, but is characterized by turning to the side opposite the discharge.

Language disturbance: Speech arrest can occur, with an abrupt loss of speech while talking. Other movements can develop on top of this. Less common is ictal jargon, where there is spontaneous speech that is unintelligible.

Loss of responsiveness: Generalized and partial seizures can manifest as disturbance of responsiveness. Absence epilepsy is the prototypic disorder with no response to command during a seizure but response delayed until after the seizure.

Fear and ictal language: Ictal fear can present with a series of statements of alarm which, unlike jargon, are easily understandable.

Contralateral posturing: Posturing may be so subtle as to be not noticed. The posturing can resemble adversive maneuvering but with posturing of limbs and head.

Autonomic symptoms: Autonomic symptoms can accompany a seizure with motor manifestations or be isolated symptoms of seizures (Moseley et al., 2012). Autonomic symptoms can be almost anything in the arena, but ones of greatest importance include tachyarrhythmias, bradyarrhythmias, hyperventilation, episodic abdominal pain, nausea, vomiting, flushing of the skin, and even sexual symptoms.

Oroalimentary automatisms: Oral automatisms can include lip smacking and chewing.

Generalized Seizure Activity

Seizure Patterns

Generalized seizures have their origin in the circuits that are responsible for cortical-subcortical associations. A such, there is not a single focus, so these seizures are unlikely to be due to a structural lesion. These are primary-generalized seizures rather than secondarily generalized seizures.

Generalized seizures come in several important types, including:

- Absence;
- Atypical absence;
- Tonic-clonic;
- Myoclonic.

Absence seizures are staring spells without loss of postural tone. This is associated with the 3-per-second spike-wave pattern.

Atypical absence seizures include the Lennox-Gastaut syndrome. There is loss of awareness. The differentiation from absence is mostly by EEG where the discharge is slower, about 2.5/sec. In contrast with absence, there is slower loss of awareness and more gradual recovery.

Tonic-clonic seizures are one of a family of motor seizures that also includes tonic and clonic seizures. EEG pattern is spike-wave of a variety of frequencies.

Myoclonic seizures include juvenile myoclonic epilepsy. In addition, there is benign myoclonus and myoclonus associated with metabolic disorders.

The EEG activity associated with generalized seizures comes in four common patterns, although some less common patterns do occur.

EEG Patterns

The common patterns are:

- 3-per-second spike-wave;
- Slow spike-wave (about 2.5/sec)
- Fast spike-wave (about 5/sec);
- Fast polyspike-wave (about 6-7/sec).

3-per-Second Spike-Wave Pattern

The 3-per-second spike-wave pattern (Figure **4-117**) is typically seen in patients with absence epilepsy, although other seizure types may be seen, including generalized tonic-clonic seizures. The discharge is synchronous from the two hemispheres and begins with discharge at about 4/sec then slows to about 2.5 during the duration of the discharge. The discharge is maximal over the midline frontal region, and is minimal in the temporal and occipital regions. The individual waves consist of a spike, double spike, or polyspike component and a following slow wave. Patients who show the polyspike complex are more likely to exhibit myoclonus.

Figure 4-117:

Typical 3-per-second spike-and-wave discharge.

Hyperventilation provokes the 3-per-second spike wave complex. If absence epilepsy is considered, then hyperventilation should be performed for 5 minutes rather than the usual 3 minutes. Children with absence epilepsy are typically identified by the observer as symptomatic if the discharge lasts longer than 5 seconds. The technician should ask a question during the discharge and note the timing and type of subsequent response.

Fast Spike-Wave Pattern

The fast spike-wave complex is seen in primary generalized epilepsies and correlated with generalized tonic-clonic seizures with or without myoclonus (see Figures **4-118** and **4-119**). Absence seizures are rare.

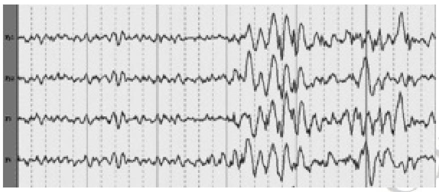

Figure 4-118:

This discharge has a high frequency of approximately 5 Hz.

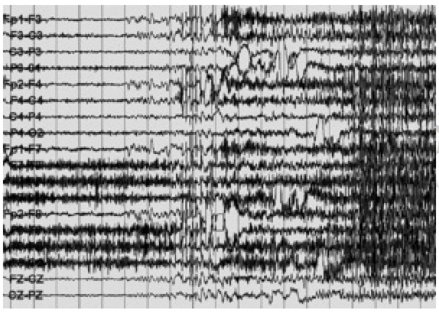

Figure 4-119:

The fast spike-wave complex has a frequency of 4–5/sec and has the appearance of slow waves with superimposed sharp activity, rather than a distinct spike-wave complex. This pattern is less stereotyped than the 3-per-second spike-wave pattern, with less synchrony.

Slow Spike-Wave Pattern

The slow spike-wave complex (Figure **4-120**) has a frequency of 2.5/sec or less. The morphology is less stereotyped than the 3-per-sec spike-wave complex. The duration of the slow spike is usually more than 70 msec, which technically makes it a sharp wave. The complex is generalized and synchronous across both hemispheres, with the highest amplitude in the midline frontal region. During sleep, the slow spike-wave complex may be continuous, but this is thought to be activation of interictal activity during sleep rather than status epilepticus.

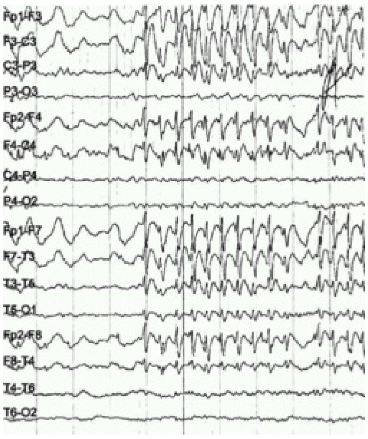

Figure 4-120:

The slow spike-wave complex is often associated with the Lennox-Gastaut syndrome (LGS). The term *petit-mal variant* is misleading and should not be used. The slow-spike-wave pattern in LGS is often an interictal pattern but may be ictal. Since the patients have a mixed seizure disorder, ictal patterns may be other than the slow spike-wave complex. Atonic seizures shows generalized spikes during the myoclonus, followed by the slow spike-wave complex during the atonic phase. Atonic seizures are most characteristic of LGS. Akinetic seizures show the slow spike-wave complex throughout the seizure. Tonic seizures occur in LGS and are characterized by rapid spike activity or desynchronization rather than the slow spike-wave complex.

Hypsarrhythmia

Hypsarrhythmia is a pattern that is usually easily recognizable by the experienced neurophysiologist (Figures **4-121**, **4-122**, and **4-123**). The pattern is characterized by high voltage bursts of theta and delta waves with multifocal sharp waves superimposed. The bursts are separated by periods of relative suppression. In some circumstances, flattening of the EEG may be an ictal sign, indicating that there has been sudden desynchronization of the record.

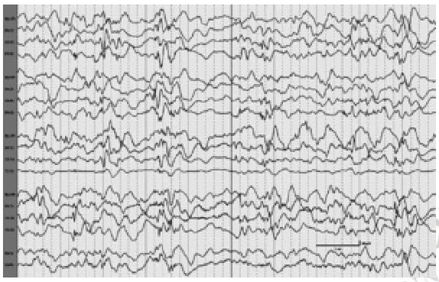

Figure 4-121:

EEG shows high voltage slow disorganized background with multifocal spikes and periods of relative attenuation

Figure 4-122:

The period of attenuation corresponded to a clinical spasm.

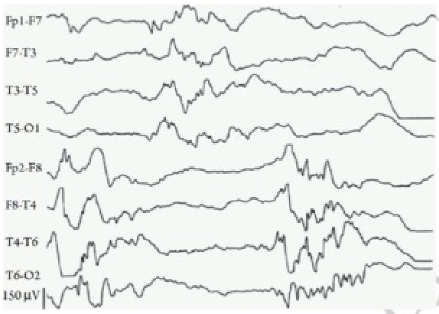

Figure 4-123:

The periods of attenuation are asynchronous, suggesting Aicardi syndrome.

Hypsarrhythmia is seen particularly in patients with infantile spasms. Patients with symmetric hypsarrhythmia seldom have structural lesions, whereas patients with asymmetric or unilateral hypsarrhythmia are more likely to be associated with structural lesions.

6-per-Second (Phantom) Spike-Wave

6 Hz spike-and-wave discharges recorded in the posterior head region can be a normal variant, seen predominantly in young women. This has been termed *FOLD* (referring to preponderance in Females, Occipital predominance, Low-voltage, and occurrence in Drowsiness).

6Hz spike-and-wave discharges that are anterior in localization are more likely associated with epilepsy. These have been termed *WHAM* (referring to Waking, High voltage, Anterior localization, and Male predominance).

These acronyms were described by Hughes (1980). In summary:

- WHAM = Waking record, High amplitude, Anterior, Males;
- FOLD = Females, Occipital, Low amplitude, Drowsy.

WHAM is associated with seizures, but FOLD is not. The seizures associated with the anterior/frontal discharge are generalized tonic-clonic.

The complex is composed of brief trains of small spike-wave complexes, distributed evenly over both hemispheres, with either a frontal or occipital predominance, as described. They are most commonly seen during the waking and drowsy states, and disappear with sleep.

The sample shown in Figures **4-124** and **4-125** is from a 10-year-old female. The spikes reverse at Pz.

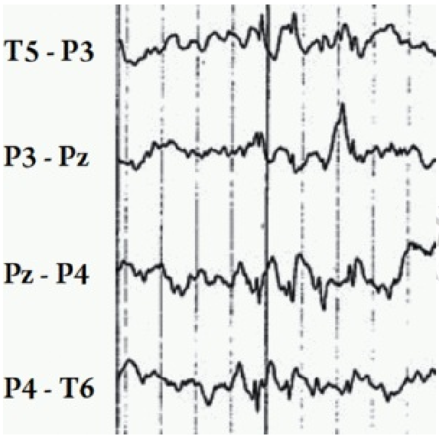

Figure 4-124:

An entire page is shown below.

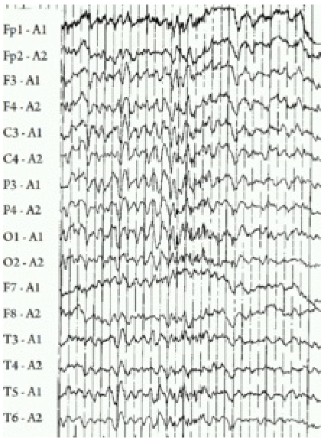

Figure 4-125:

Absence Seizures

Overview

Absence seizures are among the most common observed in clinical practice. Children may show these seizures on routine examination or during a routine EEG with hyperventilation. Typical of absence epilepsy are the following features:

- Seizures characterized by loss of awareness with or without automatisms;
- Provocation of the seizures by hyperventilation;
- No postictal confusion;
- Normal examination;
- Normal EEG background, other than the 3-per-second spike-wave discharges.

Seizures may be multiple during the day, and initially passed off as inattention or daydreaming. Recognition of the automatisms may prompt the clinical suspicion and diagnosis. EEG is usually abnormal, showing brief 3-per-second discharges with an otherwise normal background.

Treatment is usually with ethosuximide, valproate, or lamotrigine. Patients often have total control of their seizures with monotherapy. The EEG usually dramatically improves with treatment, and there may be no interictal discharge with patients on therapeutic AED levels, a feature not typical of many epilepsies.

EEG of Absence Seizure

The recording in Figures **4-126** and **4-127** shows the typical 3-per-second spike-wave pattern. The pattern is not as well developed at the beginning of the discharge, then becomes better developed through the duration.

Figure 4-126:

This shows the onset and early evolution of the 3-per-second spike-wave discharge.

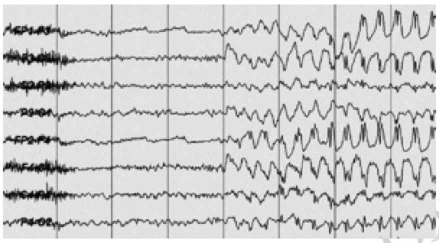

Figure 4-127:

This is a magnified portion of figure **4-126** to more clearly show the onset of the discharge. The EEG component of this recording shows a rhythmic 3-per-second spike-wave pattern, which slows slightly during the recording. This slowing is especially prominent with prolonged seizures. There is a rapid return to normal intellect following the seizure.

The 3-per-second spike-wave pattern is typically seen in patients with absence epilepsy, although other seizure types may be seen, including generalized tonic-clonic seizures. The discharge is synchronous from the two hemispheres and begins with discharge at about 4/sec, then slows to about 2.5/sec by the end of the discharge. The discharge is maximal over the midline frontal region, and is minimal in the temporal and occipital regions. The individual waves consist of a spike, double spike, or polyspike component and a following slow wave. Patients who show the polyspike complex are more likely to exhibit myoclonus.

Hyperventilation provokes the 3per-seccond spike-wave complex. If absence epilepsy is considered, then hyperventilation should be performed for 5 minutes rather than the usual 3 minutes. Children with absence epilepsy are typically identified by the observer as symptomatic if the discharge lasts longer than 3-5 seconds. The technician should ask a question during the discharge and note the timing and type of subsequent response.

Absence Without Spikes

Occasionally, absence seizures are seen without the spike component visible on surface recordings (see Figure **4-128**). There are no clinical implications. This is a controversial area, but is rarely seen in routine recordings (Lee and Kirby, 1988).

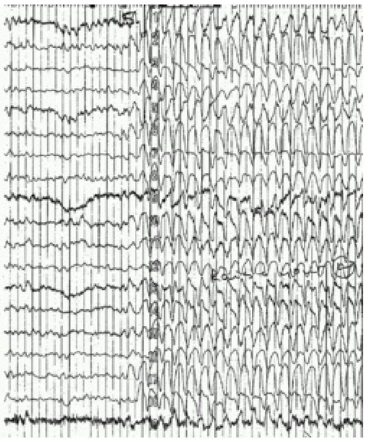

Figure 4-128:

The seizure shows a typical 3-per-second wave without the spike being apparent.

Absence with Preserved Awareness

Patients with absence seizures may show preserved awareness although responsiveness is impaired and delayed.

Myoclonic Absence

Myoclonic absence is characterized by absence seizures with a myoclonic component. This is more prominent motor activity than is seen with the automatisms associated with absence seizures.

Absence with Self-induction

Absence can rarely be self-induced, such as by waving the hand in front of the eyes while brightly illuminated (Figure **4-129**). This is the ultimate manifestation of non-compliance, where the patient intentionally provokes a seizure for the experience.

Figure 4-129:

Atypical Absence Seizures

Overview

Atypical absence seizures tend to occur in symptomatic generalized epilepsy such as Lennox-Gastaut syndrome. The main distinction between typical and atypical absence seizures is electrographic, as the latter have a slower frequency of less than 2.5 Hz. This is the slow spike-wave pattern. Clinical distinctive features reported are a slower loss of awareness and a more gradual recovery, as well as perhaps more prominent motor manifestations.

The term *petit-mal variant* is misleading and should not be used.

Atypical Absence Seizure Presentation

Atypical absence seizures usually begin in early childhood, under the age of 6 years, and continue into adult life. Not all patients have the Lennox-Gastaut syndrome. Cause can be genetic or due to perinatal insult. The atypical absence seizures should be differentiated from typical absence and from daydreaming and inattention. Other differential

diagnoses include complex partial seizures, although these are unusual to have onset in early childhood.

Lennox-Gastaut syndrome (LGS) is a severe epilepsy characterized by mixed seizures including atypical absence, atonic, tonic, and myoclonic. Seizures have onset usually before the age of 4 years. Development is usually abnormal, with intellectual impairment and behavioral abnormalities. Cause can be genetic or due to a variety of perinatal insults. Seizures persist into adult life. The slow-spike-wave pattern in LGS is often an interictal pattern but may be ictal.

Since the patients have a mixed seizure disorder, ictal patterns may be other than the slow spike-wave complex. Atonic seizures show generalized spikes during the myoclonus, followed by the slow spike-wave complex during the atonic phase. Atonic seizures are most characteristic of LGS. Akinetic seizures show the slow spike-wave complex throughout the seizure. Tonic seizures occur in LGS and are characterized by rapid spike activity or desynchronization rather than the slow spike-wave complex.

Treatment is often difficult with incomplete response to monotherapy. AEDs most commonly used are valproate, lamotrigine, felbamate, and topiramate.

EEG of Atypical Absence Seizures

The EEG in patients with atypical absence seizures is characterized by slow spike-wave pattern. The slow spike-wave complex has a frequency of 2.5/sec or less. The morphology is less stereotyped than the 3-per-sec spike-wave complex. The duration of the slow spike is usually more than 70 msec, which technically makes it a sharp wave. The background is also often abnormal, in contradistinction to absence, with slowing and disorganization.

The complex is generalized and synchronous across both hemispheres, with the highest amplitude in the midline frontal region. During sleep, the slow spike-wave complex may be continuous, but this is thought to be activation of interictal activity during sleep rather than status epilepticus.

Patient #1

Figure **4-130** shows the slow spike-wave pattern typical of atypical absence seizures. Figure **4-131** is a second epoch from the same patient.

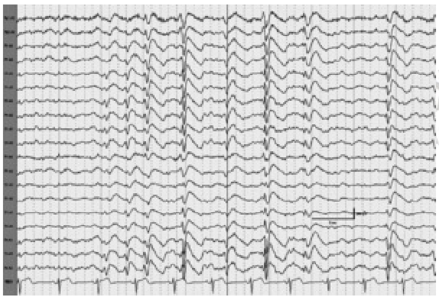

Figure 4-130:

Slow spike-wave pattern with atypical absence seizure.

Figure 4-131:

Second epoch from the same patient.

Patient #2

The slow spike-wave pattern can look similar to the 3-per-second spike wave pattern, with the main differentiating features being slower frequency, disorganization, and abnormal background, the latter of which is the most helpful in clinical practice (Figure **4-132**).

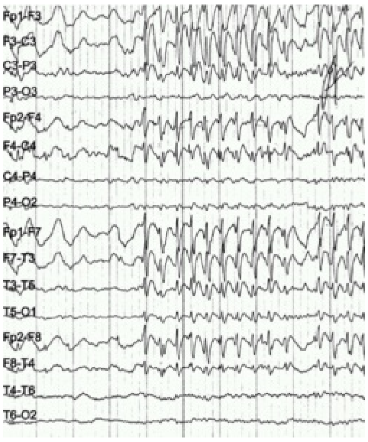

Figure 4-132:

Generalized Tonic-Clonic Seizures

Overview

Generalized tonic-clonic seizures may occur in many generalized epileptic syndromes. The EEG appearance at onset may vary with the specific syndrome. For example, Figure **4-133** shows the onset of a generalized tonic-clonic seizure in a patient with juvenile myoclonic epilepsy.

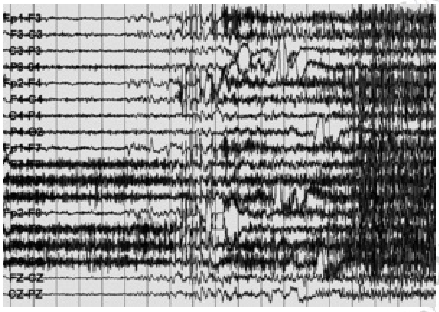

Figure 4-133:

In patients with generalized absence and generalized tonic-clonic seizures, absence seizures may secondarily evolve into tonic-clonic seizures.

Generalized Tonic-Clonic Seizure Presentation

Generalized tonic-clonic seizures are characterized by shaking and tonic contraction of the extremities. The discharge is most commonly fast spike-wave, but can also be 3-per-second spike-wave or polyspike-wave. The generalized tonic-clonic seizure shown in these Figures is primarily generalized, but tonic-clonic seizures can also be secondarily generalized from a partial seizure. In this circumstance, the focal onset may or may not be seen clinically.

EEG Appearance of Generalized Tonic-Clonic Seizure

Figures **4-134** and **4-135** are from the same patient and show the beginning and peak-ictal period. While discharges are visible initially, with major motor movements, the EEG can be obscured by EMG and movement.

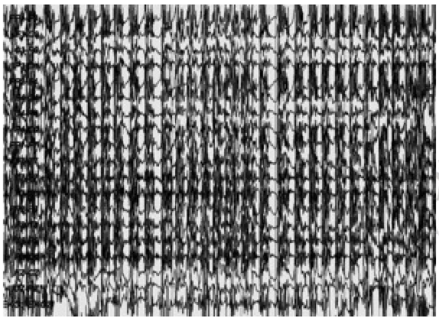

Figure 4-134:

Continuation of the seizure shown in Figure **4-133**.

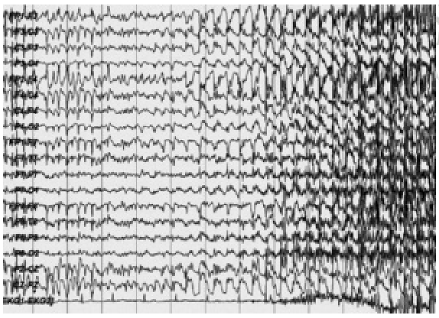

Figure 4-135:
Figure **4-134**.

Evolution of a Tonic-Clonic Seizure

EEGs from three patients with generalized tonic clonic seizures are shown to demonstrate the initial evolution of the discharge. The first (Figure **4-136a** and **4-136b**) is from a patient previously discussed with JME. The other two are from different patients showing patterns of evolution (Figures **4-137** and **4-138**)

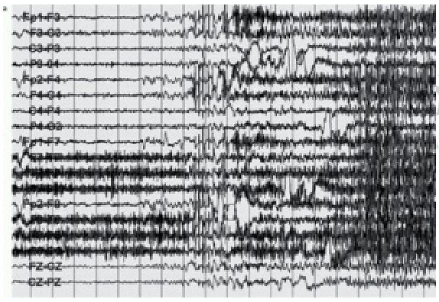

Figure 4-136a:

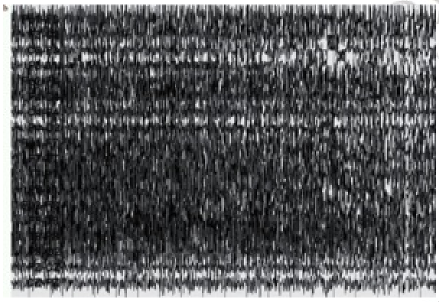

Figure 4-136b:

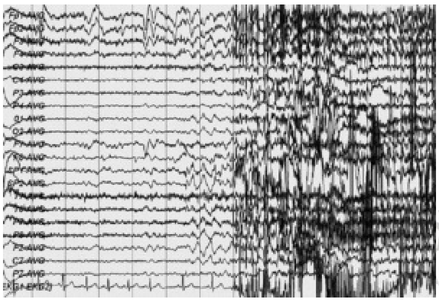

Figure 4-137:

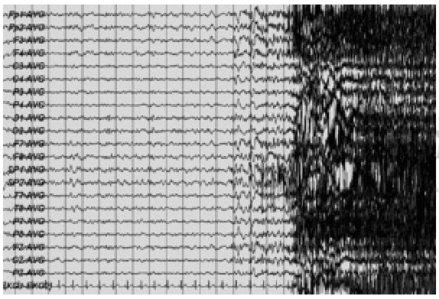

Figure 4-138:

Generalized Tonic Seizures

Generalized tonic seizures are brief episodes of increase in tone, lasting only a few seconds to about 1 minute. The manifestation can be an increase in neck tone or upward eye deviation, but may be more severe with marked increase in tone of the axial and appendicular muscles. Neck and trunk flexion are most common along with shoulder abduction and hip flexion. The seizure may start with a myoclonic jerk. They usually start in sleep and drowsiness.

Tonic seizures may be followed by atypical absence, resulting in what appears to be a more prolonged postictal state. This has been termed a *tonic-absence seizure*.

EEG of Generalized Tonic Seizure

The EEG shows a fast spike pattern that shows evolutionary changes (Figures **4-139** and **4-140**).

Figure 4-139:

The discharge as shown is fast with evolutionary changes in frequency.

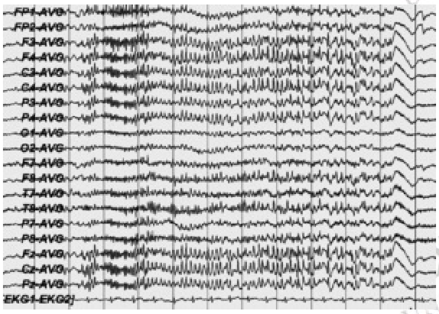

Figure 4-140:

The EEG epoch in Figure **4-141** is not associated with overt clinical changes. This demonstrates slow spike-and-wave activity. This is a characteristic finding in the EEG of patients with Lennox-Gastaut syndrome.

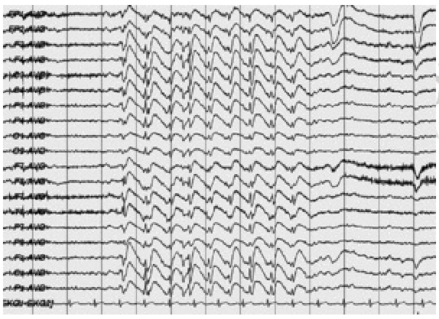

Figure 4-141:

Tonic-Absence Seizures

Tonic-absence seizures are characterized by tonic activity followed by inattentiveness or impaired responsiveness. These usually occur in symptomatic generalized epilepsy. Patients usually have tonic seizures without the prolonged absence.

The patient is a 17-year-old with seizures since infancy, following meningitis at 7 months of age. The seizure is characterized by a brief tonic phase followed immediately by the absence phase. The tonic portion of the activity is longer and slower than myoclonus, with a contraction that is slightly sustained.

The epoch in Figure **4-142** was recorded using the longitudinal-bipolar montage; Figure **4-143** is the same epoch presented in an ear reference montage.

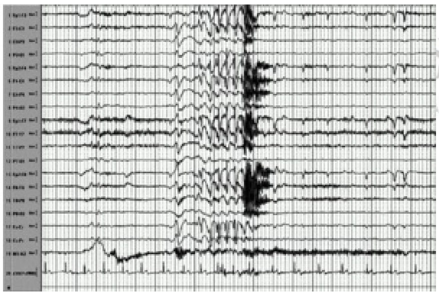

Figure 4-142:

Figure 4-143:

Generalized Atonic Seizures

Atonic seizures are episodes of loss of tone. They most commonly begin in childhood and continue into adult life. These seizures can vary in manifestation from subtle drooping of the head to a massive loss of tone with falling. They are more common in children. They are associated with drop attacks. Drop attacks can be due to tonic seizures as well, and the distinction of the two can be difficult without direct observation.

Myoclonic atonic seizures (Figure **4-144**) have a brief myoclonic component to an atonic seizure. These seizures are commonly part of the syndrome of myoclonic astatic epilepsy, also referred to as *Doose's syndrome*. In these seizures, a myoclonic jerk precedes the loss of tone. The seizures are very brief with rapid recovery. However, injuries are not uncommon with a fall from loss of tone.

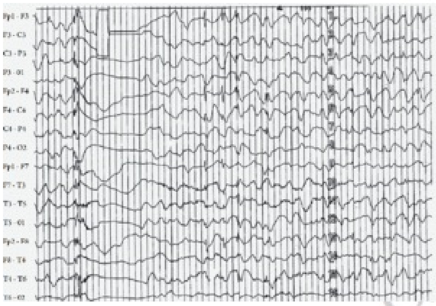

Figure 4-144:

Atonic seizures can be induced by stimuli and activities, such as eating. This is a form of reflex epilepsy.

Myoclonic Seizures

Generalized myoclonic seizures last a fraction of a second. They vary in severity from mild with barely visible twitch to severe with massive myoclonus associated with falling. The myoclonic jerk may involve the whole body, or the upper extremities, or the head alone. Although they are usually bilateral, they could be unilateral with shifting lateralization. Myoclonic seizures are not associated with loss of consciousness because of their very brief duration. They often occur in clusters, and patients occasionally report some disruption of consciousness with a cluster of closely spaced seizures.

Subsets of myoclonic seizures include:

- Juvenile myoclonic epilepsy.
- Myoclonic-atonic seizure..
- Myoclonic seizures with developmental delay.

The EEG in Figure **4-145** is of a 16-month-old patient with developmental delay. The seizures are characterized by neck flexion and arm extension. The EEG of this patient shows high-voltage discharges; note the calibration signal, which indicates 200 µV.

Figure 4-145:

Figure **4-146** is another discharge from the same patient. This is a longer duration discharge, again associated with myoclonus.

Figure 4-146:

Primary reading epilepsy is characterized by seizures occurring exclusively in association with reading, as differentiated from secondary reading epilepsy, where patients may have spontaneous seizures of differing types. This is shown in the section on Simple Partial Seizures. The seizures often are myoclonic movements of the jaw.

The classification of seizures in primary reading epilepsy is uncertain, but the seizures in reading epilepsy seem to respond to the same agents effective in generalized myoclonic seizures.

Myoclonic-Absence Seizures

Myoclonic-absence seizures are rare and mainly occur in childhood, with a mean onset of about 7 years of age. Episodes are characterized by rhythmic myoclonic jerks, most prominently of the upper arms and shoulders. The head and/or legs can also be involved. The arms may sometimes elevate slightly during the jerking (Bureau and Tassinari, 2005a,b).

The EEG in myoclonic-absence shows a 3-per- second spike-wave pattern, which may have a spike- wave or polyspike-wave appearance. The discharge and the symptoms are usually symmetric. Motor activity is synchronous with the discharge.

Consciousness is variably impaired, and some patients can retain the ability to continue some simple normal activities.

Myoclonic absences are seen as an isolated entity and also in association with developmental delay and ataxia. The seizures are difficult to control. Valproate and/or ethosuximide are commonly used. Alternatives include lamotrigine, levetiracetam, and topiramate.

Epileptic Spasms and Infantile Spasms

Epileptic spasms have a characteristic appearance. They have gone by a number of names including *infantile spasms*. *Epileptic spasms* is presently a preferred term but historically referred to similar episodes outside the infantile age group.

West syndrome is the combination of infantile spasms and mental retardation. The term is sometimes used as a synonym for infantile spasms itself.

Case: Infantile Spasms in a Patient with Lissencephaly

These recordings (Figures **4-147** through **4-148**d) are all from the same patient in the same recording session. This is a 2-year-old with lissencephaly and uncontrolled seizures. The baseline-interictal recording shows disorganized, high-voltage activity with multifocal sharp waves and spikes, many followed by brief generalized attenuation.

Figure 4-147:

Figure 4-148a:

The first frame (Figure **4-148**a) shows disorganized high-voltage background with multifocal sharp waves. A brief spasm is shown near the middle of the recording, with high-voltage, high-frequency activity followed by suppression. The background returns to near baseline by the end of this frame (Figure **4-148**d).

Case: Child with Perinatal Asphyxia

Figure **4-149** shows the EEG of a 9-month-old with a history of perinatal asphyxia and developmental delay. The child has subtle infantile spasms with movements including neck flexion and elevation of the arms.

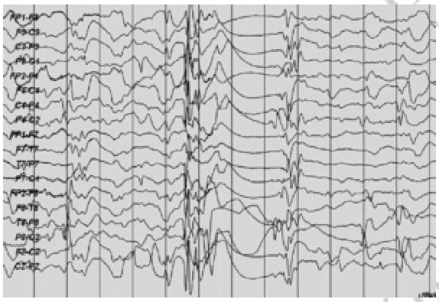

Figure 4-149:

EEG prior to onset showed high-voltage slow activity, with multifocal spikes. At seizure onset, there is generalized attenuation with high-frequency (beta-range) activity. After several seconds, the EEG returns to the prior pattern.

Focal Epileptiform Activity and Partial-Onset Seizures

Overview

Focal epileptiform discharges are the interictal hallmark of partial epilepsy. They include spikes, sharp waves, and combinations of the above with slow waves. By definition, spikes last less than 70 msec, whereas sharp waves last 70 msec to 200 msec. When recorded from the scalp, discharges shorter than 20 msec are unlikely to be cerebral or epileptiform. A number of features help distinguish between epileptiform and non-epileptiform sharp activity. All these features may not be present at once, but the more features there are, the more confident one can

Figure 4-148b:

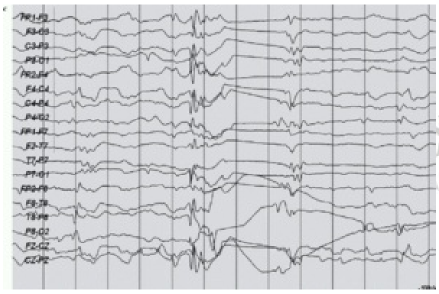

Figure 4-148c:

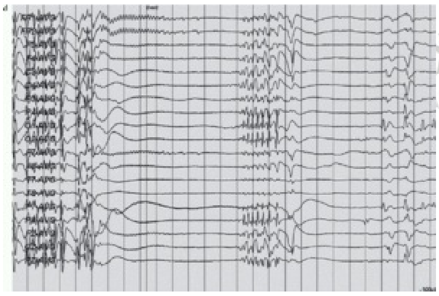

Figure 4-148d:

be of the epileptiform nature of the discharges. These features include:

- A high-voltage, a biphasic or polyphasic morphology with a primarily negative polarity,
- An asymmetric appearance, typically with a steeper first phase, and an after-going slow wave.

In addition, epileptiform discharges usually:

- Arise from an abnormal background,
- Stand out from normal rhythmic activity occurring in their area, and
- Have a consistent identifiable field that cannot be explained by artifact.

A spike or sharp wave seen only from a single electrode should be interpreted with caution. It is highly unusual for an epileptiform discharge to be noted in a single electrode in an adult individual. If the field involves a neighboring electrode even slightly, there would be greater confidence in calling the epileptiform discharge.

With this in mind, a single spike or sharp wave in a recording should not be reported as indicative of epilepsy. If the conformation is worrisome, comment should be made in the interpretation, and re-study should be considered.

Interictal epileptiform discharges are recorded in approximately 50% of first EEGs. However, the yield increases to approximately 90% with repeated or prolonged recordings in patients with well-documented epilepsy. The likelihood of recording discharges varies with the epileptic syndrome and the seizure type. In partial epilepsy, the location and orientation of the cortex generating discharges is important in determining whether discharges appear on recordings. For example, discharges generated by medial frontal cortex may be invisible on EEG because the dipole orientation is parallel to the surface. Other discharges partially generated in fissures may have such a dipole orientation that both negative and positive ends of the dipole are seen. This is referred to as a horizontal dipole. It is very common in benign rolandic epilepsy.

Interictal epileptiform discharges generally correspond well to the ictal seizure focus, particularly when they have a single consistent field. When the interictal epileptiform discharges are bilateral or multifocal, it is still possible that there is a single seizure focus. For example, it is also not unusual for epileptiform discharges to be bitemporal independent, while seizures arise only in one temporal lobe. The interictal epileptiform discharge focus on the side opposite the seizure focus is frequently referred to as *mirror focus*. Although the side of greater epileptiform activity generally turns out to be the seizure focus, there are exceptions to this rule. At times, interictal epileptiform discharges are temporal when the ictal seizure focus is extratemporal. One potential explanation may be that sharp waves arising in the seizure focus are invisible on EEG due to dipole orientation.

Spikes and sharp waves may correspond to a focal structural lesion that could be evident on routine imaging, or visible only on pathological examination. However, they may also be seen without underlying structural abnormality. This is particularly true for epileptiform discharges arising outside the seizure focus.

Truly epileptiform discharges may be seen in the absence of epilepsy. This is most likely in children, and is particularly true for occipital and rolandic spikes, as well as for generalized epileptiform activity. In addition, there are a number of benign variants that have a sharp configuration, but have no clinical significance. These include physiologic activity with sharp configuration (such as K-complexes, positive occipital sharp transients of sleep, Mu activity), and benign variants such as sporadic spikes of sleep (also called small sharp spikes [SSS] or benign epileptiform transients of sleep [BETS]), 14- and 6-Hz positive spikes, and wicket spikes.

The appearance of ictal discharges is dependent predominantly on the seizure type and on the seizure localization. Seizures of focal onset may be remain focal or may become widespread or secondarily generalized. At times, the initial focal onset is invisible, because its localization makes it invisible to scalp electrodes and because secondary generalization occurs very quickly.

Simple partial seizures can arise in any lobe. However, due to the limited field of cortical involvement in this seizure type, simple partial seizures are not associated with EEG changes in 60–80% of instances. When EEG changes are seen, they may be focal rhythmic activity with a narrow field or periodic sharp activity. Complex partial seizures are

most likely to arise in the temporal and frontal lobes, but may also arise in the parietal and occipital lobe.

Presented here are examples of seizures of different focal origins.

Temporal Lobe Focus

Temporal lobe focus is the most common source of focal seizures. Patients with seizures of temporal lobe origin often have auras that may be isolated (simple partial seizures) or may progress to complex partial seizure. Just as isolated simple partial seizures often have no EEG correlate, it is common for the first EEG change to be seen late in the aura or in transition to the complex partial phase.

Patients with a temporal lobe focus may have simple partial or complex partial seizures. These seizure types may coexist in the same patient.

Frontal Lobe Focus

Auras of frontal lobe origin are most commonly a non-specific cephalic sensation. Seizures may have a variety of clinical features, depending on the site of origin in the frontal lobe. Primary motor cortex focus results in simple partial seizures with focal clonic or tonic motor activity. Supplementary motor cortex activity also produces simple partial seizures associated with posturing. Cingulate and orbitofrontal foci produce complex partial seizures.

Parietal Lobe Focus

The most common aura with a parietal lobe focus is a sensory aura. If there is a march to the aura, the origin is most likely in the post-central primary sensory cortex. Less common symptoms include vertigo and inability of localizing a limb in space. The seizure may be sensory, may progress to involve focal motor activity or tonic posturing, or may become complex partial with immobile staring or automatisms. Parietal lobe seizures frequently spread to the temporal lobe or to the frontal lobe to produce manifestation typical of these lobes.

Occipital Lobe Focus

Occipital foci usually produce a visual aura, which may be an elementary visual sensation or complex hallucinations. Visual illusions may also be noted. Seizure progression will depend on seizure spread. Ictal blindness may occur. Occipital lobe seizures may spread to the temporal lobe or to the frontal lobe to produce manifestations typical of these lobes.

Case: Temporal Lobe Focus with Simple Partial and Complex Partial Seizures

This patient is a 24-year-old female with intractable simple partial and complex partial seizures. In childhood, she had been diagnosed as having meningitis and encephalitis on separate occasions. She became seizure-free after right temporal lobectomy, and is off AEDs. The EEG (Figure **4-150**) shows right temporal lobe focus, which is seen best with special electrodes including sphenoidal electrodes and additional temporal scalp electrodes.

Figure 4-150:

The subsequent EEG (Figure **4-151**) shows a simple partial seizure. Note the restricted field of the discharge. The next EEG (Figure **4-152**) shows a complex partial seizure in the same patient. Note the wider field of spread. MRI (Figure **4-153**) shows prominent right hippocampal sclerosis with atrophy and increased signal intensity on this T2-weighted image.

Figure 4-151:

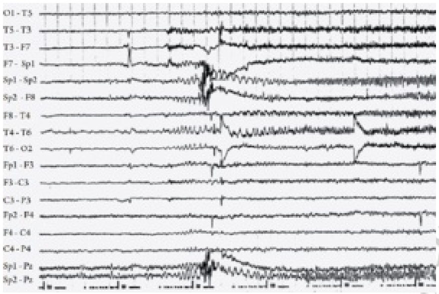

Figure 4-152:

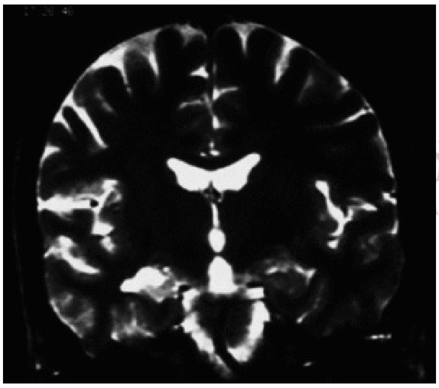

Figure 4-153:

Simple Partial Seizures

Overview

Simple partial seizure is characterized by focal sharp activity that is usually most prominent in the central region. Interictal abnormalities are common and usually are sharp, although focal slowing can occur, especially in patients with focal structural lesions. Ictal discharge consists of repetitive spiking from the focus, although focal slowing can also be seen. The sharp component of the discharge may be subtle or missing if the epileptiform activity is generated in a portion of the cortex deep to the scalp.

Partial seizures can spread throughout the hemispheres resulting in a generalized seizure. Secondary-generalized seizures may have a focal onset that can be detected clinically, but this is not always the case. The generalization may occur so quickly that the focal onset can only be determined by EEG, and not by clinical appearance.

Clinical Appearance

Simple Partial Adversive Seizure

An 18-year-old male with right occipito-parietal angiomatosis has simple partial adversive seizures. He had previously had seizure surgery in this region 12 years ago. He recently had recurrence of seizures.

EEG (Figure **4-154**) shows prominent muscle artifact in the left hemisphere and right frontal derivations. There is also rhythmic activity in the right frontocentral region. This first Figure is LB montage, but the localization is easiest to see on the average derivation shown after this.

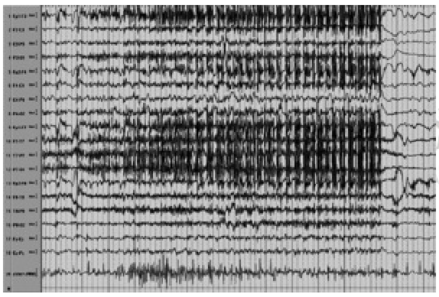

Figure 4-154:

Figure **4-155** is the Ave montage with the same EEG epoch. Localization is easier on this montage. Note that the artifact is more left-sided (frontotemporal), whereas the ictal discharge is predominantly right-sided. Figure **4-156** is the LB montage again, with a 20-second window rather than a 15 second window, and is at a lower sensitivity.

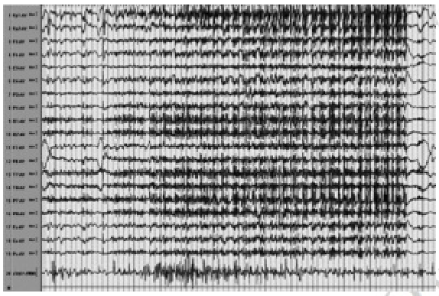

Figure 4-155:

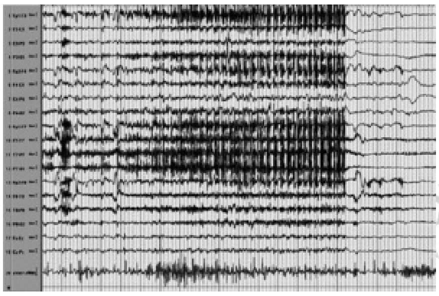

Figure 4-156:

Subjective Simple Partial Seizure

Not all seizures are characterized by visible seizure activity.

Simple Partial Seizure in a 24-Year-Old with Hippocampal Sclerosis

In this example, the patient reports subjective symptoms. This is a 24-year-old female with seizures since age 7 years. This is the same patient described above for complex partial seizures. The seizures begin with an epigastric sensation of butterflies in the stomach. She has isolated subjective seizures. In addition, she has complex partial seizures with staring, oroalimentary automatisms, and right arm dystonic posturing. Figure **4-157** shows the interictal activity seen in this patient. The EEG epoch in Figure **4-158** shows the seizure onset. The MRI (Figure **4-159**) shows another view of the right hippocampal sclerosis.

Figure 4-157:

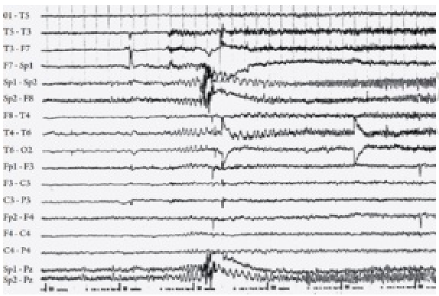

Figure 4-158:

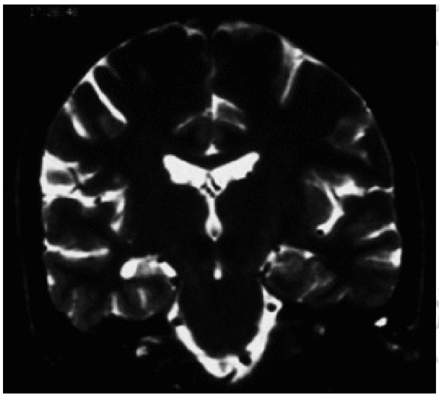

Figure 4-159:

Right hippocampal sclerosis.

Simple Partial Seizure with Clearly-Defined Focus at C3

This is a 6-year-old left-handed male with tuberous sclerosis and seizures since 2 months of age. Seizures include flexion of the right arm with extension of the fingers and sometimes fisting beside the ear.

The EEG (Figure **4-160**) shows a clearly defined focus maximal at C3. This would be a rolandic localization, although not benign rolandic epilepsy.

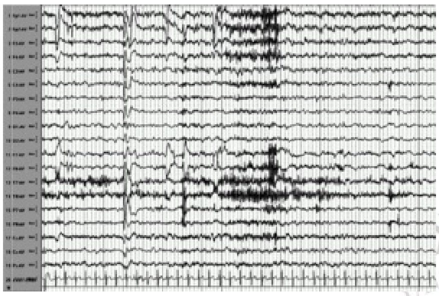

Figure 4-160:

Secondary Reading Epilepsy

This is a 27-year-old female with a prior history of complex partial seizures of left temporal origin, which became controlled with left temporal lobectomy. Subsequently, she developed recurrence of rare complex partial seizures that were controlled with AED. Three years following surgery, she noted that her mouth jumped while she was reading, both aloud and silently.

EEG (Figures **4-161** and **4-162**) shows subtle findings of a discharge at about C3 in association with the facial jerks.

Figure 4-161:

Figure 4-162:

Simple Partial Seizure with Midline Discharges

Simple partial seizures can be produced by foci in various regions. Vertex spike activity is occasionally seen. Figure **4-163** shows the interictal activity seen in this patient.

Figure 4-163:

Frontal Focus

Partial seizures with a frontal lobe focus can produce a range of clinical manifestations. Among the most common are simple partial clonic movements. These can exhibit secondary generalization with tonic-clonic seizures.

Supplementary Motor Seizure

Supplementary motor seizures are a form of simple partial seizure with the origin in the mesial frontal lobe. Supplementary motor seizures may be unilateral or bilateral. Interictal and ictal abnormalities are seen near the midline in some patients, although intracranial electrodes may be necessary to see the discharge.

A 23-year-old female has had intractable partial seizures since her teens. She was clinically thought to have non-epileptic seizures. She was found to have a left supplementary motor area (SMA) focus with grid electrodes. Scalp EEG shows bilateral parasagittal sharp waves at seizure onset, followed by attenuation and muscle artifact (Figures **4-164a** through **4-164c**). Two seconds before seizure termination, a left parasagittal rhythmic theta discharge is seen.

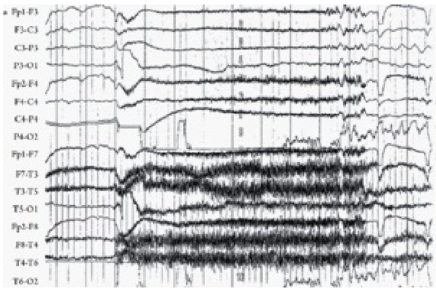

Figure 4-164a:

Figure 4-164b:

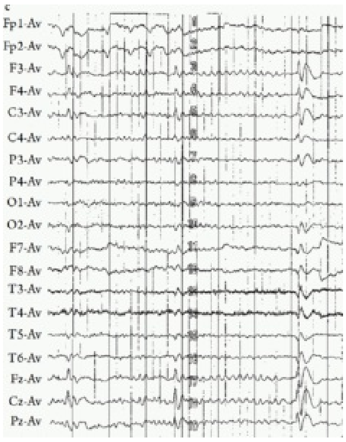

Figure 4-164c:

Parietal Focus

Focal seizures in the parietal region are much less common than frontal or temporal seizures. The example in Figures **4-165a** and **4-165b** is from a patient with a mesial centro-parietal seizure focus.

Figure 4-165a:

Figure 4-165b:

Occipital Focus

This series of Figures (**4-166a** through **4-166k**) is from a single patient with occipital discharge progression to secondarily generalized tonic-clonic seizure.

Figure 4-166a:

Figure 4-166k:

Rolandic Epilepsy or BECTS

Rolandic epilepsy is a disorder of childhood, characterized by discharges from the central regions, especially the regions of C3 and C4. The interictal discharges are independent, although findings from both sides are usually seen during a routine recording. Sleep augments the discharges. Earlier in this chapter the clinical features were discussed in more detail and in that section the title was benign epilepsy with centrotemporal spikes (BECTS). Here is another clinical example.

The sample EEG (Figure **4-167**) shows a reversing focus between the C4 and P4 electrodes on this transverse bipolar montage. Relatives of patients with rolandic epilepsy may manifest the discharges without clinical seizures.

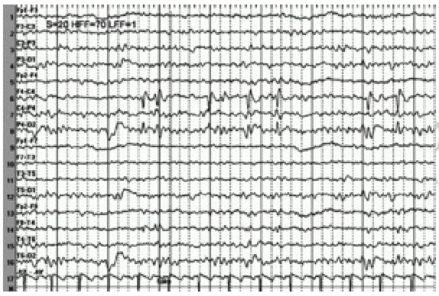

Figure 4-167:

Rolandic discharge, with reversal most prominent between the C4 and P4 electrodes.

This location is in the right centro-parietal region.

Complex Partial Seizures

Overview

Complex partial seizures are associated with focal discharges that are usually in the temporal lobe but may be in the frontal or other regions. The temporal lobe focus is not always visible on routine surface EEG, and may be missed without special electrodes or techniques. Sphenoidal, nasopharyngeal, and depth electrodes can be used to identify the discharge. Interictal activity shows focal slowing or sharp activity in the temporal region (or elsewhere). The interictal activity is not associated with behavioral change, by definition. Ictal discharge may be repetitive spike activity with disturbance of the EEG background. Alternatively, the spike component may not been seen in scalp electrodes, so there may be either no abnormal recording or repetitive slowing, associated with the seizure.

Use of Special Electrodes for Complex Partial Seizures

Special electrodes are occasionally needed in order to precisely localize spike discharges in patients with complex partial seizures. The Figures that follow show the results of focal seizures of varying localization.

Sphenoidal Electrodes

Sphenoidal electrodes are used for assessment of the mesial temporal region. In Figure **4-168**, the discharge is seen well on sphenoidal derivation; however, it is virtually invisible with routine scalp electrodes.

Figure 4-168:

Foramen Ovale Electrodes

The example in Figure **4-169** is of a patient with complex partial seizures who has independent left and right temporal sharp waves. The last lines of the EEG are made using electrodes in the proximity of foramen ovale.

Figure 4-169:

Localization of the discharge is important for identification of a site for surgical treatment. The recording shown in Figure **4-170** is of the beginning of a seizure, and shows activity in the foramen ovale leads several seconds prior to the discharges appearing on the cortex.

Figure 4-170:

Complex Partial Seizures with Left Temporal Focus

Overview

Left temporal lobe focus is commonly identified in video-EEG monitoring. This is usually the dominant hemisphere, so language difficulty is common. The language changes may be speech arrest or ictal jargon. The first example shows a patient with postictal aphasia. Later, there is ictal jargon.

Case: Left Lateral Temporal Focus

This is a 43-year-old with intractable seizures since age 3, starting with ringing in the ears, then trouble hearing, and right-hand numbness.

Figure 4-166b:

Figure 4-166c:

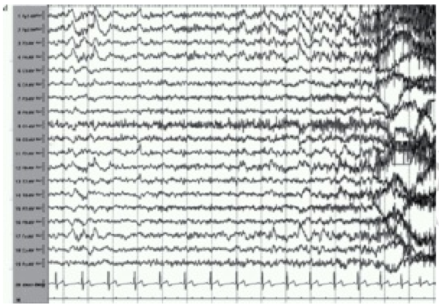

Figure 4-166d:

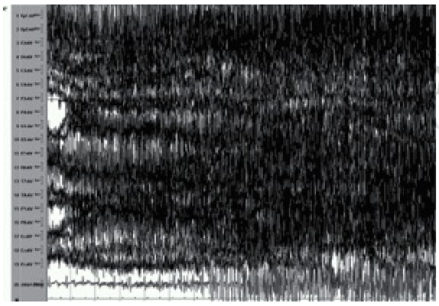

Figure 4-166e:

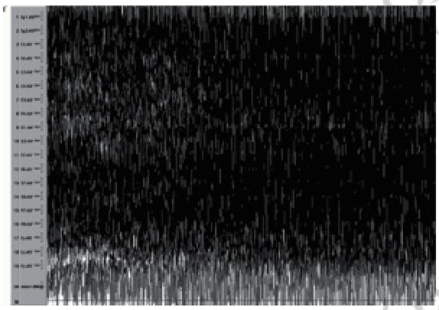

Figure 4-166f:

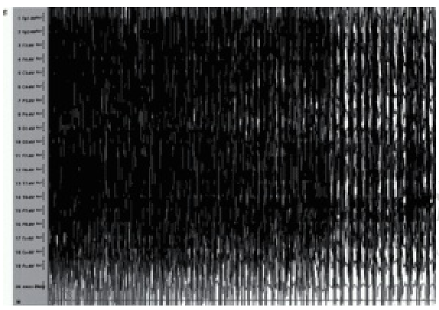

Figure 4-166g:

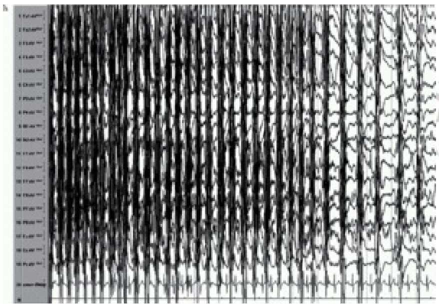

Figure 4-166h:

Figure 4-166i:

Figure 4-166j:

The EEG (Figure **4-171**) shows a focus in the left lateral temporal lobe. The same discharge evolves into sustained seizure activity (Figure **4-172**).

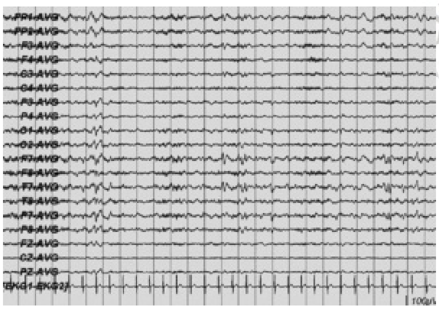

Figure 4-171:

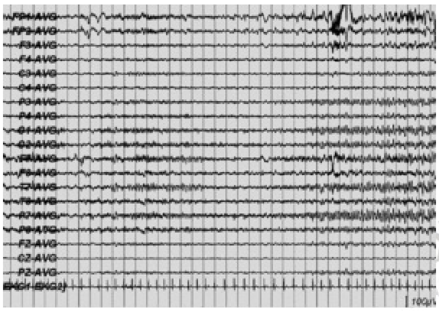

Figure 4-172:

Complex Partial with Secondary Generalization

This is a 26 year-old female with intractable seizures since age 17 (Figures 7-173 through **4-175**). The seizures start with inability to understand language. The CPS include early head turning to the left. There is late head turning to the right with secondary generalization. She was found to have a left temporal cavernous angioma, as shown on the MRI slice.

Figure 4-175:

The MRI (Figure **4-176**) from this patient shows a cavernous angioma in the left temporal region, which correlates well with the localization of the EEG.

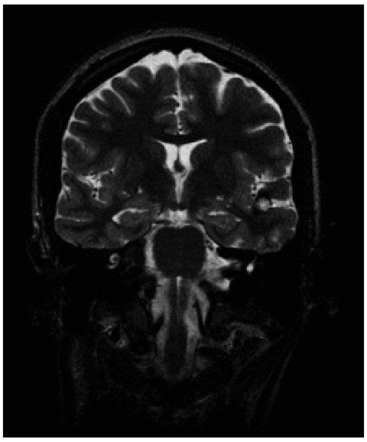

Figure 4-176:

CPS with Postictal Aphasia

This patient with complex partial seizures has a focus in the left temporal area. She loses awareness during the seizure and has decreased responsiveness. After the event, there is postictal aphasia (Figure **4-177**a). The seizure develops with increased frequency of the repetitive activity and obscuration of the background (Figure **4-177**b). The seizure continues with increased frequency of the repetitive activity (Figure **4-177**c).

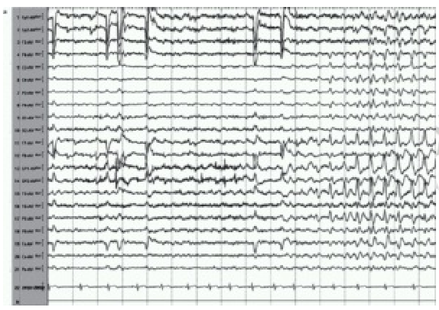

Figure 4-177a:

The seizure continues with slowing of the discharge with continued disorganization of the background (4-177d). The termination of the seizure and postictal period are characterized by slow-down of the epileptiform activity and postictal slowing (Figure **4-177**e).

Complex partial seizures with right temporal lobe focus.

Well-formed ictal language and partially preserved responsiveness in the presence of oroalimentary automatisms suggest non-dominant temporal lobe origin. In this example, the patient appears to have preserved responsiveness, but has no memory of the event.

This patient has a right temporal lobe focus and shows preserved responsiveness during the seizure (Figure **4-178**a). Figure **4-178b** shows a continuation of the seizure activity.

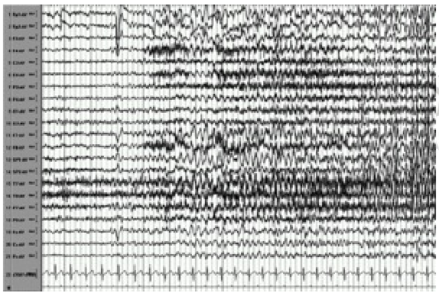

Figure 4-173:

This EEG epoch shows rapid generalization of the focal discharge.

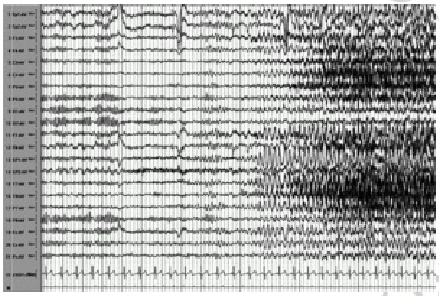

Figure 4-174:

The left temporal sharp wave as a focus for the seizure is clearly seen on this recording, in the F7 and T7 electrodes.

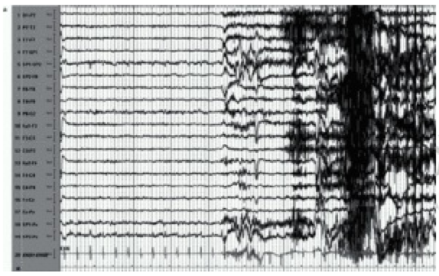

Figure 4-178a:

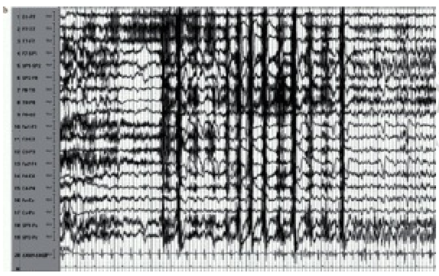

Figure 4-178b:

Complex Partial Seizures with a Frontal Focus

Overview

Complex partial seizures (CPS) due to frontal lobe foci are less common than temporal lobe foci. Clinical differentiation from seizures of temporal origin is imperfect, but some general guidelines were discussed above.

CPS with Left Frontal Focus

This is a 38-year-old male who presented with seizures since 5 years of age. The onset of the seizure appears gradual, with clear global aphasia, while there is preservation of some responsiveness. Although unable to speak, he retains the ability to smile.

The EEG shows interictal discharges which are most prominent at F7, which could be interior frontal or anterior temporal (Figure **4-179a**). The MRI (Figure **4-179c**) gives the anatomic localization to the frontal region. The discharge becomes more rapid and spreads with development of the seizure (Figure **4-179b**).

Figure 4-179a:

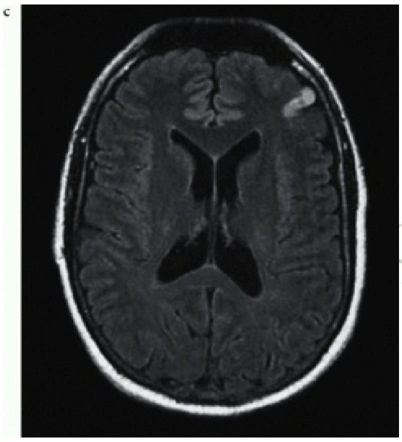

Figure 4-179c:

Figure 4-179b:

The MRI of this patient is shown in Figure **4-179c**. On the basis of EEG appearance, differentiation between posterior frontal and anterior temporal was not possible, but the lesion is in the frontal lobe.

Figure 4-177b:

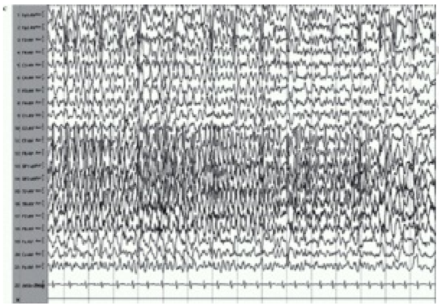

Figure 4-177c:

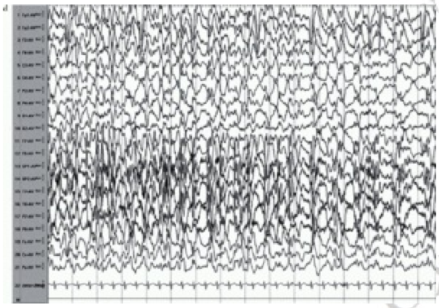

Figure 4-177d:

Figure 4-177e:

Gelastic Seizures

Gelastic seizures are characterized by episodes of laughter, which can be very similar to spontaneous laughter. However, the timing and onset of the laughter is inappropriate. It can be seen in association with partial, myoclonic, tonic, tonic-clonic, and even absence seizures.

Differentiation from normal laughter is associated ictal activity, prolonged duration, and absence of provoking comedic stimulus.

Figues **4-180a** and **4-180b** show interictal discharges in a patient with gelastic seizures. Figure **4-180c** shows ictal discharge in the same patient.

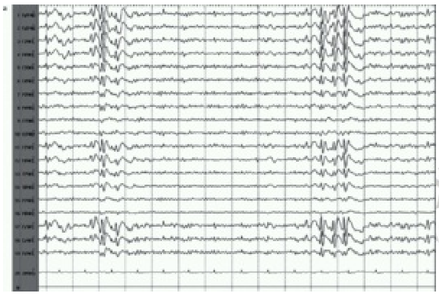

Figure 4-180a:

Figure 4-180b:

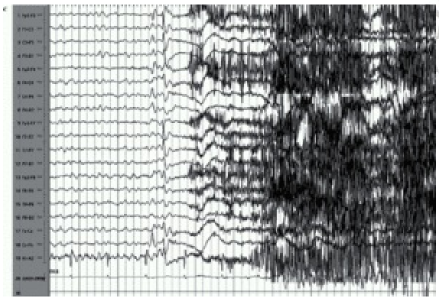

Figure 4-180c:

Partial-Onset Seizure with Secondary Generalized Tonic-Clonic Seizure

This is the same patient as is shown in CPS with left temporal focus with postictal aphasia (here). In this seizure, the complex partial seizure becomes secondarily generalized (Figures **4-181a** through **4-181j**).

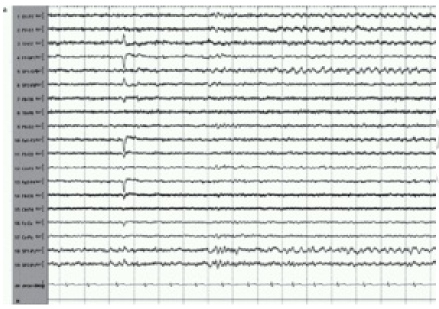

Figure 4-181a:

Figure 4-181b:

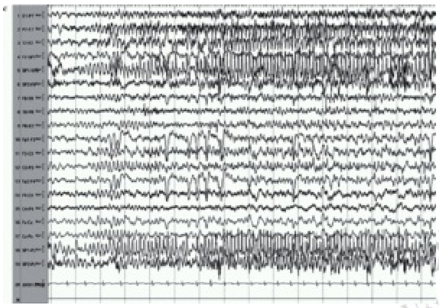

Figure 4-181c:

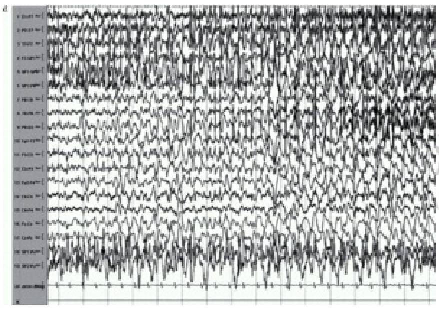

Figure 4-181d:

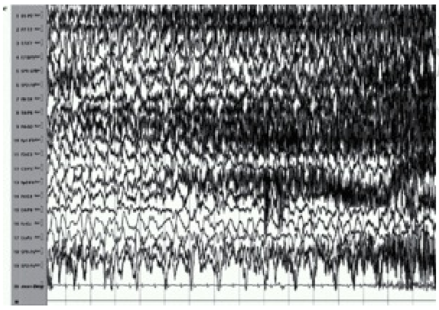

Figure 4-181e:

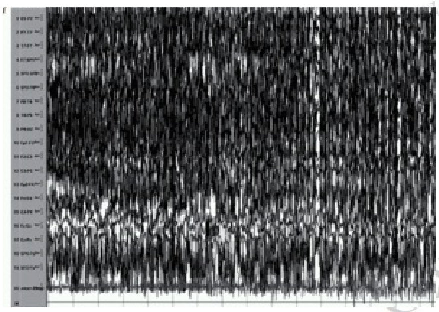

Figure 4-181f:

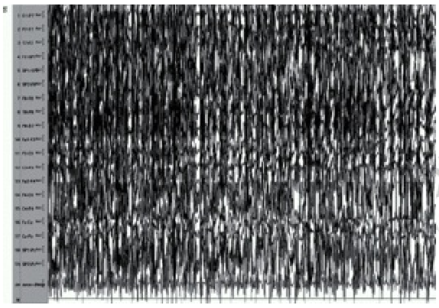

Figure 4-181g:

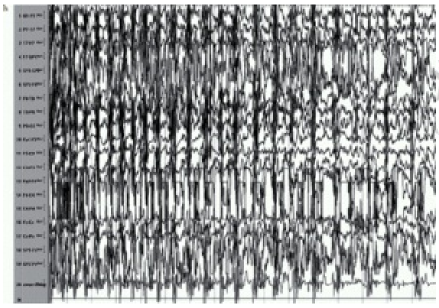

Figure 4-181h:

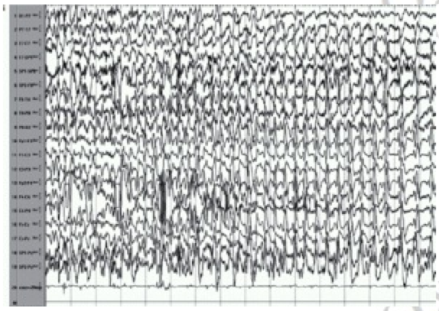

Figure 4-181i:

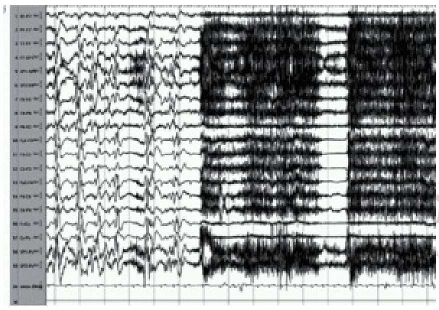

Figure 4-181j:

Abnormal Pediatric EEG

This section concentrates on findings that are specific for children. Many of the abnormalities already described affect children as well as adults, but detailed description will not be presented here.

Neonatal EEG Abnormalities

Neonatal EEG abnormalities usually fall into one of the following groups:

- Abnormality of maturation;
- Epileptiform activity;

- Background abnormality.

These are described in Table 4-20 and will be described subsequently in more detail.

Table 4-20 Neonatal EEG Abnormalities

Type	*Pattern*	*Description*
Abnormality of maturation	Dysmature	EEG background appears younger than conceptional age. Suggests encephalopathy
Epileptiform abnormality	Focal discharges	Consistent localization of sharp waves, as opposed to normal sharp transients. Often occur in trains.
	Multifocal discharges	Multifocal sharp waves or spikes with an abnormal background, as opposed to normal multifocal transients.
	Rhythmic activity	Rhythmic activity in the alpha or theta range is typically abnormal and can be epileptiform even in the absence of a sharp component.
	Pseudo-beta-alpha-theta-delta	Ictal discharge beginning in the beta range and slowing to the delta range.
Background abnormality	Excessive slow activity	Excessive slow activity can be difficult to diagnose with already prominent delta. Pathologic delta is more widespread and lacks reactivity.
	Low voltage background	Low voltage suggests global cortical dysfunction. At the extreme of this, the isoelectric EEG can be a confirmatory test for brain death.
	Burst suppression pattern	Burst suppression can be difficulty to differentiate from discontinuous pattern, but when seen indicates serious cerebral functional disturbance.
	Asymmetric background	Asymmetry in background suggests a functional or structural lesion usually affecting the side with the lower and less rich activity. Amplitude asymmetries are usually only significant for a difference of 50% or more. Intracranial and extracranial fluid collections are a common cause.

Abnormality of Maturation

Dysmature pattern is typically an EEG appearance that is younger than expected for conceptional age. For example, a discontinuous pattern with an interburst interval of more than 1 minute would be normal at 26 weeks conceptional age but would be distinctly abnormal at 34 weeks. A dysmature pattern is interpreted as encephalopathy, but no specific etiology can be inferred from these data.

Persistent dysmaturity is associated with poor neurologic outcome, but transient dysmaturity can be associated with no neurologic sequelae.

Epileptiform Activity

Epileptiform abnormalities in neonates can have markedly difference appearance from epileptiform abnormalities in older children and adults. The abnormalities are usually focal or multifocal but seldom generalized since pathways facilitating generalization are not fully developed.

Focal discharges are usually central, right or left. Differentiation from normal sharp transients is usually by a consistent localization of pathologic sharp waves and occurrence of abnormal sharp activity in trains; normal sharp transients do not occur in trains. Trains of discharges can have an unimpressive sharp component so that they appear like a run of fast activity in the alpha or theta range, but rhythmic activity in neonates is not normal, helping with differentiation from normal activity. Differentiation of rhythmic fast activity from a normal delta brush is by absence of the underlying delta wave and longer duration of the rhythmic train with seizure activity (Figure **4-182**).

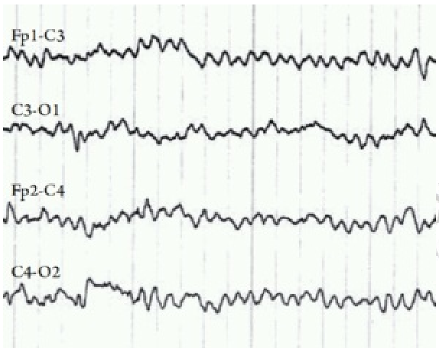

Figure 4-182:

Focal discharges often correlate with focal seizures, but the correlation between discharge location and clinical motor manifestation is not as good as in older children and

adults. Also, focal discharges in neonates do not have as strong a correlation with focal structural lesion as in older individuals. Most epileptiform discharges are surface-negative, as in older individuals. Surface-positive discharges are seen in some infants with intracerebral hemorrhage, but this correlation is far from highly sensitive or specific.

Multifocal discharges are differentiated from normal multifocal sharp transients by an otherwise abnormal background, occurrence of the discharges in trains, and associated clinical seizures. The seizures may be subtle but are usually clonic.

Pseudo-beta-alpha-theta-delta is descriptive pattern of a discharge that starts at high frequency and slows. Beginning frequency is usually at least 8–12/sec and the frequency slows to 0.5–3/sec. The appearance can be smooth or sharp. Associated seizures are clonic, myoclonic, or subtle, and as such this is an ictal pattern. The most common cause is perinatal asphyxia, often with a poor prognosis. The decrease in frequency can have the appearance of dropping to a harmonic of an original frequency.

Seizures in neonates, as in older patients, occasionally are associated with no EEG abnormality on scalp recording. In these circumstances, the generator is likely subcortical or at least not involving cortex close to the scalp where the electrodes are. Seizures of subcortical origin in neonates usually indicate severe damage with the failure of cortical projection being a manifestation of this damage.

Background Abnormality

State changes might not be seen during the 20 minutes of a routine EEG, but in long-duration recordings, if there are not changes in state, then this is abnormal.

Excessive slow activity is difficult to identify in neonates since delta is such a prominent part of the record. Abnormal delta tends to be unilateral or diffuse whereas normal delta is symmetrically regional (e.g., anterior). Abnormal delta tends to not respond to stimulation with attenuation, but this lack of reactivity is normal in very young prematures.

Amplitude asymmetries are abnormal if at least 50% and consistent. Usually there are differences in frequency composition associated with amplitude asymmetry as well. Note that both intracranial and extracranial pathology can result in amplitude asymmetry; for example, subdural hematoma and scalp hematoma can both produce attenuation of EEG over the affected area.

A low-voltage EEG is usually abnormal in non-REM sleep and usually indicates a global abnormality in cortical function. Note that REM sleep might be associated with a low-voltage background, so recording of non-REM sleep is important. Also, bilateral subdural hematomas can produce symmetric attenuation, and therefore may be missed on EEG.

Isoelectric EEG can be a confirmatory test for brain death in neonates, but there are special considerations concerning diagnosis of brain death in neonates, as discussed above.

Burst-suppression can be difficult to differentiate from a normal discontinuous pattern. Implication is usually a global cerebral process such as anoxia. Burst suppression is differentiated from a normal discontinuous pattern, usually by knowledge of conceptional age with an expectation of the degree of discontinuity, reactivity of the background if the patient is old enough, and clinical information.

We frequently observe a disconnect in appearance of the EEG and clinical appearance of premature infants. Pre-term infants can manifest markedly abnormal neurologic exam with little or no abnormality in EEG and vice versa. Suffice it to say that the EEG and the examination are evaluated independently and then interpreted in concert.

Pediatric EEG Abnormalities

Many of the abnormalities seen in the pediatric population are discussed in the broad presentation of epileptiform and non-epileptiform abnormalities. Some findings are shared between children and adults (e.g., focal and generalized spikes or slowing). But some are specific to a pediatric population (e.g., hypsarrhythmia).

Abnormalities Dependent on Maturation

Maturation of the EEG requires that the EEG reader's expectation of background change commensurate with the age of the patient. Posterior slow waves of youth are normal in a child through early adult life, but similar waves in middle or advanced age are likely physiologically different and pathologic. A discontinuous pattern is still seen in a normal term infant, to a certain extent, but would be distinctly abnormal at 6 months of age.

Certain EEG rhythms can look remarkably similar yet be of totally different implication depending on age. Sleep spindles in young children can be prolonged yet are normal when they first appear. Almost identical patterns in pre-term infants are not sleep spindles and can represent an ictal pattern.

A markedly discontinuous pattern is normal in a very premature infant but in an older child or adult an almost identical appearance can be a burst-suppression pattern, indicative of severe cerebral dysfunction. Similarly, this burst suppression pattern can be due to cerebral destructive process or to medication-induced coma, with distinction between these on EEG bases alone difficult if not impossible in some circumstances (Dan and Boyd, 2006).

Epileptic Encephalopathies

Young children may develop progressive encephalopathies associated with epileptic and/or myoclonic seizures. These have been classified by ILAE as *epileptic encephalopathies* (Khan and Al Baradie, 2012). In general, they tend to be refractory to many AEDs. Some of the most important types are discussed in Table 4-21.

Table 4-21 Epileptic Encephalopathies		
Disorder	***Clinical***	***EEG***
Early infantile epileptic encephalopathy (EIEE) or Ohtahara syndrome	Early seizures, even in utero. Tonic spasms especially but also tonic-clonic, clonic, myoclonic, atonic, absence, complex partial. May progress to West or Lennox-Gastaut syndrome.	Burst suppression in waking and sleep states, often asymmetric.
Early myoclonic encephalopathy	Myoclonus that can be subtle or pronounced, often shifting in location. Onset in first months. May have subtle partial seizures, tonic seizures. Epileptic spasms may develop. Developmental delay.	Burst suppression, often asymmetric. Eventually hypsarrhythmia.
Infantile spasms and West syndrome	West syndrome is triad of infantile spasms, developmental delay, and hypsarrhythmia.	Hypsarrhythmia
Severe myoclonic epilepsy of infancy (SMEI or Dravet syndrome)	Initially clonic seizures with fever in the first year. Often focal but may be generalized. Later afebrile, with myoclonic seizures and photosensitivity. Often developmental slowing with worsening seizures.	Normal early, later polyspike and spike-wave discharges, focal or generalized. Some show a photoparoxysmal response.
Childhood epileptic encephalopathy (Lennox-Gastaut syndrome or LGS)	Multiple seizure types with developmental regression. May have especially tonic, atonic, and/or absence seizures. May also have myoclonic, generalized tonic-clonic, or partial-onset seizures.	Slow spike-and-wave discharges at 1.5–2 Hz. Slow background in most, becoming more disorganized in sleep.
Acquired epileptic aphasia (AEA, Landau-Kleffner syndrome)	Progressive regression of language function in previously normal children, usually both receptive and expressive but one may predominate. Seizures in most, especially complex partial with atypical absence appearance or generalized.	Spike-and-wave discharges of high amplitude, especially temporal bilaterally, but also may be multifocal or generalized, especially in non-REM sleep.

Indeterminate EEG Patterns

Overview

Some seizures cannot be clearly characterized as partial or generalized in onset.

Generalized Clonic versus Frontal Lobe Origin Seizure

This patient shows clonic activity typical of frontal lobe focal seizure activity. Figure **4-183** shows the EEG. In this case, it is difficult to determine whether this is generalized or focal in onset since the initial discharge seems bilateral.

Figure 4-183:

Frontal Absence

Absence seizures have occasionally been demonstrated to originate in the frontal lobe, as determined by depth EEG or other methods while the EEG was indistinguishable from generalized-onset absence seizures (Figure **4-184a**).

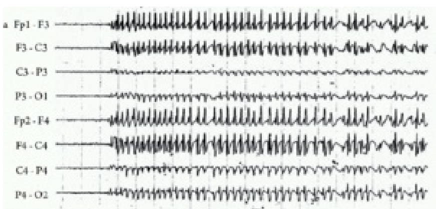

Figure 4-184a:

The example is from a 8-year-old female with a history of prematurity with congenital left hemiparesis, as well as seizures. The seizures are characterized by altered responsiveness, decreased tone, and head nodding and blinking for a few seconds. The EEG was usually consistent with generalized absence seizures; however, MRI (Figure

4-184b) showed a dysplastic right hemisphere. Ictal PET (Figure **4-184c**) revealed right frontal hypermetabolism, suggesting that the seizure originated in the abnormal right frontal lobe.

Figure 4-184b:

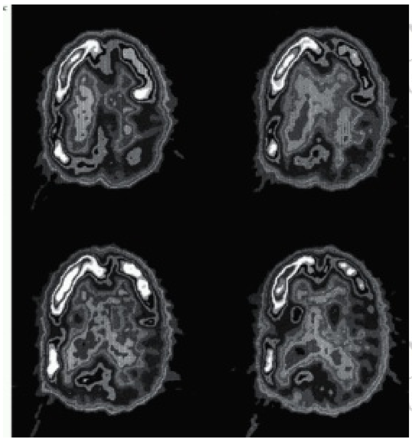

Figure 4-184c:

Advanced Techniques

Electrocorticography (ECoG)

Electrocorticography (ECoG) is performed at the time of surgery for electrode placement or resection. When used at the time of electrode placement, ECoG is an aid to determine proper location of the electrodes. For example, if ECoG shows that discharges are near the margin of a grid, then the coverage area may be revised by moved or supplemental electrodes to provide better localization.

When ECoG is used during resection, a recording is usually made before and after the resection. If the patient already had subdural strip electrodes, then these provide the pre-op recording, and the ECoG electrodes are placed for post-op recording, usually at the margins of the resection. Frequent discharges near the margins are often an indication for further surgery. Discharges that are infrequent or distant from the margin do not necessarily warrant additional surgery.

Critical Care Monitoring

Continuous critical care monitoring is increasingly used for a variety of indications. The most common are post-CPR encephalopathy and seizure monitoring.

Post-CPR encephalopathy: Encephalopathy after CPR is a common reason for neurologic consultation. Data have indicated some prognostic factors that have been relied on for years. However, with the advent and widespread use of therapeutic hypothermia, the specificity of some of these indicators has been questioned. EEG is part of the neurological evaluation, which certainly includes detailed examination and sometimes additional labs, such as neuron specific enolase. While routine EEG can be helpful, bedside EEG monitoring is often used to allow for continuous evaluation of brain activity as sedatives are withdrawn, as well as for the identification of seizures or periodic discharges.

Seizure monitoring: Patients admitted with status epilepticus often benefit from EEG monitoring, which can be done in two ways. One is continuous recording using a portable EEG machine. The other is bedside monitoring, usually limited to 2 channels. Both of these can be helpful. We find the video component of the portable device particularly helpful for atypical events.

Hospital encephalopathy: An increasing proportion of patients with marked encephalopathy associated with hospitalization, especially sepsis-associated encephalopathy, are found to have seizures (Iacobone et al., 2009; Kaplan and Rossetti, 2011). The diagnosis of these non-convulsive seizures in this population is facilitated by longer recordings, and bedside EEG monitoring can be particularly helpful for this. We believe that non-convulsive seizures in the hospital are significantly under-diagnosed.

Role of non-EEG staff in critical care monitoring: Continuous critical care EEG monitoring usually depends on critical care nursing to maintain the electrodes during ICU care and even to perform a provisional interpretation of the recordings. If there are abnormalities that deserve further review, than a physician trained in EEG interpretation must be called. The dependence of non-EEG lab staff for critical care monitoring, especially outside academic medical centers, creates the need for training for these individuals.

EEG findings in some of the common disorders seen with critical monitoring are discussed in Tables 4-22 and 4-23.

Table 4-22 Clinical Correlates to EEG Findings with Critical Illness

Finding	***Clinical correlate***
Generalized slowing	Almost any encephalopathy, including renal, hepatic, toxic, sepsis, hypoxic, endocrine.
Triphasic waves	Hepatic, renal, some toxicities including lithium and baclofen.
Periodic discharges	Symmetric—hypoxic, seizures.
	Asymmetric or unilateral—HSV encephalitis, other focal destructive lesion such as stroke.
Beta activity	Patients with coma with prominent beta are most often due to intoxication, especially benzodiazepines, but this has also been seen with other conditions, especially hypoxic encephalopathy.
Normal background	Psychogenic unresponsiveness is the most common cause of coma with normal EEG. Locked-in syndrome should be considered and repeat neuro exam performed for this possibility.

Table 4-23 EEG Findings with Specific Critical Illnesses

Disorder	***EEG finding***
Sepsis-associated encephalopathy	Slowing, sometimes seizures.
Hepatic encephalopathy	Generalized slowing. Triphasic waves.
Renal encephalopathy	Generalized slowing. Sometimes triphasic waves and seizure activity.
Herpes encephalitis	Slowing most prominent over the temporal region. Periodic lateralized epileptiform discharges are typical but not always seen; repeat study may be needed.
Hypoxic encephalopathy	Generalized slowing and suppression
Psychogenic unresponsiveness	Normal EEG. Sometimes excess beta because patient might have received benzodiazepine for non-epileptic seizures.
Stroke of one hemisphere	Focal polymorphic slowing over the region of the stroke. Sometimes periodic discharges. Sometimes seizures.

Intra-operative Monitoring

Intra-operative monitoring is not a focus of this text but is used by our institutions especially during seizure surgery. So part of the discussion on invasive electrodes pertains to intra-operative monitoring.

Mapping of epileptic foci is the most common intraoperative monitoring performed by our institutions. This includes assessment of EEG near the surgical margins for determination of recommended extent of resection to optimize se **4-180c** izure control.

EEG monitoring during carotid surgery has been used to determine the effectiveness of blood flow and hence maintenance of cerebral circulation during clamping and shunting for carotid surgery.

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Atlas of EEG, Seizure Semiology, and Management

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Seizure Semiology

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Overview

Much of seizure semiology was discussed in Chapter 4 on Clinical EEG. Details of semiology are discussed in this section with a minimum of figures. This chapter is organized starting with definition and description of the individual signs and symptoms then seizure classification and seizure types then clustering of signs and symptoms in relation to localization and lateralization of the epileptogenic zone.

Seizure Terminology

Many of the definitions below are derived from the glossary of descriptive terminology for ictal semiology, reported by the International League Against Epilepsy (ILAE) task force on classification and terminology (Blume et al., 2001). Ictal semiology refers to the signs and symptoms associated with seizures.

Motor manifestations

Motor manifestations are most often positive, with a muscle contraction that produces a movement. Negative motor manifestations, with a decrease in muscle contraction, are less common.

Elementary motor manifestations include:

- Tonic activity: sustained muscle contraction;
  - May result in a posture (usually involving contraction of several muscles).
  - Versive: sustained deviation of the eyes or the head to one side.
  - Dystonic: abnormal posture with a rotatory motion.
- Epileptic spasms: proximal and truncal tonic activity more sustained than a myoclonic jerk but yet very short in duration.
- Myoclonic: very brief contraction usually lasting less than 100 msec.
- Negative myoclonic: interruption of muscle tone for a fraction of a second.
- Clonic activity: sustained rhythmic jerking.
  - Without a march: remains in the same body part.
  - With Jacksonian march: spreads unilaterally to adjacent body parts as a result of the spread of seizure activity along the motor strip.
- Tonic-clonic activity: initial tonic posturing that evolves to clonic activity.
- Atonic: decreased muscle tone usually lasting more than 1 second.

Automatisms

Automatisms are repetitive coordinated motor activity that is not purposeful, though it may look voluntary. Automatisms are usually associated with altered sensorium and amnesia.

- Perseverative automatisms involve continuation of pre-ictal activity.
- De novo automatisms start after seizure onset.
- Oro-alimentary automatisms: lip smacking, chewing, swallowing, lip licking.
- Manual automatisms: involving the hand.

• Reactive or manipulative automatisms imply interaction with nearby objects, for example picking on bedsheets or fumbling with an object.

• Non-manipulative automatisms: rhythmic movements that are independent of environment. If involving the hand they are referred to by the acronym RINCH (rhythmic ictal nonclonic hand) movements.

• Gestural automatisms: movements commonly used to enhance speech.

• Pedal automatisms: involving the feet.

• Hyperkinetic automatisms imply a rapid sequence of movements with frenetic character. Examples are thrashing, kicking, pelvic thrusting, body rocking, bicycling motions.

• Gelastic: involuntary laughter.

• Dacrystic: involuntary crying.

Sensory phenomena

Sensory phenomena may involve any sensory modality.

• *Element* ary sensory manifestation: unformed sensations involving a single primary sensory modality, including:

  • Flickering or flashing lights, simple patterns, spots, visual loss.

  • Single tones or buzzing, humming, or ringing sounds; loss of hearing.

  • Tingling, numbness, pain, or a sense of movement; may have a Jacksonian march with sensation moving to adjacent body parts, reflecting spread of electrical activity over the sensory strip.

  • Olfactory hallucinations, most often unpleasant.

  • Gustatory hallucinations, most commonly metallic taste.

  • *Complex sensory manifestations*: seeing people or hearing music.

  • *Sensory illusions*: alteration/distortion of perception.

Experiential phenomena

Experiential phenomena include:

• Affective experiences such as fear, euphoria, sadness.

• Dysmnesic phenomena: déjà vu (inappropriate feeling of familiarity); jamais vu (inappropriate feeling of unfamiliarity).

• Dyscognitive: altered cognition, such as altered perception, memory, or executive function.

Autonomic phenomena May be subjective (most common is epigastric sensation, nausea, feeling hot) or objective (pallor, flushing, goosebumps, vomiting, flatulence).

Seizure Classification

The international classification of seizures divides seizures into two major groups, partial (or focal or local) and generalized (Commission on Classification and Terminology, 1981). The subdivision is dependent on whether the onset is in one part of one hemisphere or in both hemispheres simultaneously. Partial seizures are further subdivided into simple partial, complex partial, and partial becoming secondarily generalized. Simple partial seizures do not affect awareness or responsiveness, whereas complex partial seizures are associated with impairment or complete loss of awareness or responsiveness. Partial seizures vary remarkably in their manifestations, depending on where they originate, where they spread, and how fast they spread. Generalized seizure types include absence (typical or atypical), myoclonic, clonic, tonic, tonic-clonic, and atonic seizures. Generalized seizure types are more homogeneous in their clinical manifestations, though they have a wide spectrum of severity. Partial seizure semiology will be discussed first, based on the lobe of origin.

The 1981 International League Against Epilepsy (ILAE) Classification of Epileptic Seizures (the most commonly used classification):

I. Partial (Focal, Local) Seizures
- A. Simple partial seizures (consciousness not impaired)
  - 1. With motor symptoms
  - 2. With somatosensory or special sensory symptoms
  - 3. With autonomic symptoms
  - 4. With psychic symptoms
- B. Complex partial seizures (with impairment of consciousness)
  - 1. With simple partial onset followed by impairment of consciousness
  - 2. With impairment of consciousness at onset
- C. Partial seizures evolving to secondarily generalized seizures
  - 1. Simple partial seizures evolving to generalized seizures
  - 2. Complex partial seizures evolving to generalized seizures
  - 3. Simple partial seizures evolving to complex partial seizures evolving to generalized seizures

II. Generalized Seizures (Convulsive or Non-convulsive)
- A. Absence seizures
  - 1. Typical absence seizures
  - 2. Atypical absence seizures
- B. Myoclonic seizures
- C. Clonic seizures
- D. Tonic seizures
- E. Tonic-clonic seizures
- F. Atonic seizures

III. Unclassified Epileptic Seizures

Partial

Simple Partial Seizures

These are associated with preserved consciousness throughout the seizure. The most recent recommendations of the International League Against Epilepsy (ILAE) Commission on Classification and Terminology suggest replacing the term *simple partial seizure* with *focal seizures without impairment of consciousness or awareness* (Berg et al, 2010). However, the term *"simple partial"* is still widely used.

Simple partial seizures may have:

- Motor signs;
- Somatosensory or special sensory symptoms;
- Autonomic symptoms or signs;
- Psychic symptoms;
- Combination of the above.

When simple partial seizures are purely subjective they may be called isolated auras. The new ILAE proposal suggested dividing these seizures as either having observable motor or autonomic components or only involving subjective sensory or psychic phenomena.

The clinical manifestations of simple partial seizures depend on the brain region involved in the ictal discharge. This brain region may or may not be the epileptogenic zone; at times the clinical manifestations reflect seizure spread to adjacent or even distant regions. Despite that, seizure manifestations may have important lateralizing and localizing value. Focal clonic or tonic motor activity, somatosensory experiences, visual auras, and auditory auras have value in localization and lateralization of the epileptogenic zone. However, some auras such as odd feeling in the head or generalized body tingling are non-specific with respect to localization.

Complex Partial Seizures

Complex partial seizures involve altered consciousness during the seizure, ranging from subtle confusion to complete loss of contact. There may be some recollection of events or total amnesia. Complex partial seizures may start with loss of awareness, or may have a simple partial onset. The most recent ILAE recommended revisions suggest replacing the term *complex partial seizure* with *focal seizure with impairment of consciousness or awareness* (Berg et al, 2010). However, the term *complex partial seizure* is still widely used.

It is not always possible to tell if a seizure is simple partial or complex partial, since decreased ability to respond verbally may be due to aphasia or motor inhibition, as well as altered awareness. Complex partial seizures may manifest only with altered awareness/ confusion, or may include motor activity, most commonly automatisms. Complex partial seizures may arise from any brain region, but they most often originate in the temporal lobe, followed by the frontal lobe. The manifestations of complex partial seizures can vary with lobe of origin, as will be discussed later.

Partial Seizures Evolving to Generalized Tonic-Clonic Activity (Secondarily Generalized Tonic-Clonic Seizures)

Secondarily generalized tonic-clonic seizures may evolve directly from simple partial onset, directly from a complex partial onset, or may evolve from simple partial to complex partial to generalized tonic-clonic. The transition to secondary generalization usually involves some lateralizing features, the most important of which is versive head turning opposite the side of seizure onset. There may also be contralateral tonic or clonic motor activity. During generalized tonic contraction, there may be an asymmetry with arm extension contralateral and arm flexion ipsilateral to the seizure focus phase. This is designated *figure-of-4 posturing*. The clonic activity may be symmetrical and synchronous, or may have some asymmetry and asynchrony. The clonic activity may be more pronounced on the side of seizure onset, but may also become more prominent on the ipsilateral side late in the seizure. The clonic activity may even stop earlier on one side of the body. Late ipsilateral head deviation may be seen in some individuals. Asynchrony may produce some relatively low-amplitude side-to-side head jerking. Clonic activity usually decreases in frequency progressively, such that longer pauses develop between seizures over time. The generalized tonic-clonic phase rarely lasts more than 2 minutes. Following the end of the clonic activity, it is common to observe stertorous respiration (deep loud snoring respiration). The speed of recovery from a secondarily generalized seizure depends to a large extent on seizure duration and severity. Tongue biting is common, most often involving the side of the tongue. Incontinence of urine and less often of stools may also occur. After awakening, patients commonly report headache and generalized muscle soreness.

Partial Seizure Semiology by Localization

Symptoms and signs of partial-onset seizures can, to a certain extent, help to localize the site of origin of the discharge to one of the following lobes. Simple partial seizures do not produce alteration of consciousness, and tend to have an extratemporal focus. Complex partial seizures commonly have a temporal lobe focus and do produce alteration of consciousness. In addition to subdivision into simple and complex, seizures are classified according to site of origin:

- Temporal;
- Frontal;
- Parietal;
- Occipital;
- Insular.

Of the partial seizures, temporal origin is the most common, with frontal origin next in frequency, followed by parietal, occipital, and insular origin (see also Table 5-1).

Table 5-1 Semiology of Partial Seizures

Seizure type	***Semiology***
Temporal lobe	**Mesial temporal:** Subjective: epigastric sensation (butterflies, nausea, pain, etc.), especially rising; déjà-vu, jamais-vu; fear; olfactory or gustatory hallucination Objective: motor arrest and staring, often with oro-alimentary and extremity automatisms. Combination of ipsilateral manipulative automatisms and contralateral dystonic posturing is common in mesial temporal lobe onset.
	Lateral temporal: Subjective: auditory aura; vertigo Objective: early facial twitching; absence of oro-alimentary automatisms or pattern of contralateral dystonic posturing and ipsilateral extremity automatisms.
	Language manifestations may include speech arrest (non-specific), ictal aphasia, ictal jargon (dominant left temporal), well-formed ictal language (non-dominant temporal).
Frontal lobe	Subjective: cephalic aura; forced thought; sensory aura without a march (most often contralateral) may occur with supplementary sensorimotor seizures
	Motor cortex involvement—focal clonic or tonic-clonic activity.
	Supplementary sensorimotor area—posturing, especially proximally.
	Cingulate and orbitofrontal—CPS with gestural automatisms.
Parietal lobe	Subjective: marching somatosensory experience, sensation of movement in an extremity, feeling of body motion, or feeling of absence of an extremity; vertigoObjective (usually reflecting spread to temporal or frontal region): contralateral posturing, clonic activity, head and eye deviation, immobility, staring, oro-alimentary automatisms.
Occipital lobe	Subjective: elementary visual hallucinations.
	Objective: bilateral blinking, eye deviation, usually contralateral; temporal or frontal seizure patterns with spread outside the occipital lobe.
Insular lobe	Subjective: laryngeal discomfort, shortness of breath, and perioral paresthesias.
	Objective: dysarthria, dysphonia, hypersalivation

Frontal

The frontal lobe is the second most common source of seizures after the temporal lobe. A great variety of seizure manifestations can be related to frontal lobe origin.

Aura: An aura is less common with frontal lobe origin than with temporal lobe origin. There is only a limited specificity in auras. Autonomic auras with abdominal sensation are more likely to be of temporal lobe origin. However, frontal lobe limbic seizures may have the same autonomic auras, including epigastric sensation. These autonomic auras have been ascribed to the orbitofrontal and the cingulate regions.

Somatosensory auras are generally ascribed to activation of the primary sensory cortex. However, frontal lobe seizures originating in the supplementary sensorimotor area are frequently associated with a sensory aura due to activation of the supplementary sensory area. The sensory auras related to supplementary motor seizures generally do not have a march, are more often proximal, and may be bilateral in distribution, although a contralateral occurrence is most likely. Forced thinking may be seen with dorsolateral frontal lobe origin.

Perhaps the most common aura in frontal lobe seizures is the non-specific cephalic sensation, which has no localizing value. It has been suggested that isolated auras are a common feature of temporal lobe but not frontal lobe epilepsy. Thus, many patients with frontal lobe epilepsy deny auras that do not progress further.

Motor manifestations: Activation of the primary motor cortex is well-known to be associated with clonic activity. Focal clonic or tonic-clonic seizures therefore are most likely originating in the primary motor cortex. *Focal cortical myoclonus* is another manifestation of primary motor cortex epileptogenicity. In general, consciousness is preserved unless there has been spread of seizure activity to the contralateral hemisphere. If motor activity involves the lower extremity, this suggests mesial localization, while facial involvement suggests inferior frontal localization.

Seizures originating in the supplementary sensorimotor area tend to be *asymmetrical tonic* or postural seizures. They are characterized by posturing that can affect one limb, two limbs, or all four extremities. If the seizure origin is in the supplementary motor area, they will usually be simple partial seizures, with no alteration of consciousness. Supplementary motor seizures are a notable exception to the rule that bilateral seizure activity should be accompanied by loss of consciousness. These seizures tend to be brief in duration, tend to cluster, and tend to be predominantly nocturnal, arising out of sleep. The posturing of the extremities is predominantly proximal, while the hands and fingers or feet and toes seem to be free. Patients will frequently wiggle the distal extremities. There is often a vocalization of moaning or groaning and the patient reports being unable to breathe. Supplementary sensorimotor seizures are occasionally precipitated by startle, most commonly by unexpected auditory stimuli, less often by unexpected somatosensory stimuli.

Seizures originating in the supplementary sensorimotor area may occasionally manifest with inhibition of movement. There may be ictal paralysis or just inhibition of motion without paralysis, with loss of ability to move or speak. These seizures are usually simple partial or may start as simple partial seizures with later altered awareness. The ictal paralysis may be followed by positive motor (tonic or clonic) activity in the same affected extremity, or may be accompanied by positive motor activity in a different body part on the same side. The ictal inhibition is presumed secondary to seizure activity in a negative motor area, often seen adjacent to the supplementary sensorimotor area.

Since the seizure origin is in the mesial frontal cortex, there is often no recorded interictal or ictal EEG activity due to the unfavorable dipole orientation. These seizures are frequently misdiagnosed as psychogenic. The correct diagnosis is reached upon observation of evolution to secondary generalized tonic-clonic seizure activity after the withdrawal of anti-epileptic drug therapy in the epilepsy monitoring unit.

Bizarre complex partial seizures have been ascribed to seizure origin in the cingulate gyrus or orbitofrontal region, but they may also arise in other regions of the frontal lobe and even outside the frontal lobe, usually manifesting after spread to the cingulate gyrus or orbitofrontal region. Such seizures are frequently characterized by frenetic gestural automatisms (also referred to as *hypermotor behavior*) that are often bilateral, unless there is associated contralateral posturing. These automatisms can be bizarre and can be associated with bizarre vocalizations and verbalizations, including expletives. These seizures tend to be short and associated with only brief postictal manifestations, unless there is spread to the temporal lobe. The presence of unilateral posturing and rotation along the body axis, such as with turning prone, favor a mesial frontal origin, while severe agitation favors an orbitofrontal localization. Again, the clinical features and the frequent absence of interictal epileptiform activity, as well as absence or artifact masking of rhythmic ictal EEG activity, have frequently resulted in the misdiagnosis of psychogenic seizure events.

Gelastic seizures, which are short seizures characterized by sudden unprovoked laughter, are best known as a seizure type originating from hypothalamic hamartomas. However, they may also be seen with frontal cingulate as well as mesial-basal temporal seizure origin. Frontal and hypothalamic gelastic seizures are usually not associated with emotion, while temporal gelastic seizures seem to be. The gelastic seizures of frontal cingulate and hypothalamic origin may have preserved awareness, while those of temporal origin are associated with altered awareness after the initial sense of mirth. Frontal gelastic seizures may be accompanied by hypermotor manifestations or tonic posturing.

Seizures originating in the anterior-mesial frontal region at times imitate absence seizures through rapid secondary bilateral synchrony. These seizures are frequently referred to as *frontal absences*. They can clinically be characterized by altered responsiveness and arrest of activity for a few seconds with rapid return to baseline, with minimal postictal manifestations. Such seizures can be totally indistinguishable from generalized absence seizures, except for the presence of a frontal lesion, and at times the presence of consistent asymmetry on EEG. Frontal lobe origin seizures can imitate a variety of other generalized seizure types, including generalized tonic, generalized atonic, and generalized tonic-clonic seizures. Frontal lobe seizures are recognized to have a more rapid spread to the contralateral hemisphere. This is partly why falling (drop attacks) and incontinence seem more likely with frontal lobe seizures.

Seizures originating in the frontal operculum are characterized by hypersalivation, oral-facial apraxia, and at times facial clonic activity.

Seizures originating in the dorsolateral frontal lobe may manifest with tonic posturing of the extremities and versive eye and head deviation. The head deviation preceding secondary generalization is contralateral, but early head turning can be in either direction.

The lateralizing value of signs in frontal lobe seizures may be less than with temporal lobe seizures, due to the propensity for rapid contralateral spread and contralateral hemisphere activation.

It is important to recognize that seizures originating in the frontal lobe, particularly in the orbitofrontal region, may manifest after propagating to the temporal lobe, with semiology typical of mesial temporal lobe seizures.

Temporal

Temporal lobe epilepsy (TLE) is the most common symptomatic/cryptogenic partial epilepsy. The characteristic manifestations of temporal lobe seizures have long been recognized. However, the advent of video EEG monitoring and its use in presurgical evaluation have had a great impact on the understanding of temporal lobe seizure semiology. Temporal lobe epilepsy is often refractory to medical therapy, and is often amenable to surgical treatment. The surgical outcome is dependent on accurate localization of the epileptogenic zone. The analysis of clinical semiology in patients who were seizure-free after temporal lobectomy versus those still experiencing seizures has helped to identify manifestations characteristic of temporal lobe origin, and those that suggest extratemporal localization. In addition, specific seizure manifestations were analyzed for their lateralizing and localizing value within the temporal lobe (see Figure **5-1**).

Figure 5-1:

Seizure Aura

Most patients with TLE report a seizure aura. This is particularly true in mesial TLE, by far the largest TLE group. In a selected patient group with proven mesial temporal lobe origin, more than 90% of patients reported an aura. The most common was an epigastric aura. Although no aura is totally specific for temporal lobe seizures, some are very strongly associated with a temporal lobe origin, particularly viscerosensory (such as epigastric sensation) and experiential or psychic auras (such as “deja-vu”). Both of these types of aura are more likely with right temporal foci, but this is only a trend. Whereas viscerosensory auras are generally more common in mesial TLE associated with hippocampal sclerosis, experiential auras and deja vu in particular are more common in the benign familial temporal lobe epilepsy syndrome.

Multiple sequential auras in the same seizure suggest a non-dominant localization most often temporal. Chills and goosebumps are more common with left temporal foci, and if they are unilateral, they are usually ipsilateral to the seizure focus. Olfactory and gustatory auras are uncommon mesial temporal lobe epilepsy auras. They are associated with mesial temporal tumors. An auditory aura is very suggestive of lateral temporal origin. This can be a positive (buzzing or ringing sound) or negative symptom (loss of hearing). The auditory aura is a hallmark of an autosomal dominant form of temporal lobe epilepsy. Cephalic auras (non-specific sensation in the head) are more likely extratemporal. The same is true of somatosensory and visual auras. Absence of an aura is more likely with bitemporal epilepsy.

Motor Manifestations

The complex partial phase of mesial temporal lobe seizures usually starts with motor arrest or motionless staring, oro-alimentary automatisms, or non-specific extremity automatisms.

Oro-alimentary automatisms, mainly lip smacking, chewing, and swallowing movements, are suggestive of temporal lobe involvement. However, they are not specific for temporal lobe epilepsy. They may reflect the spread of seizure activity to the temporal lobe from other locations, and can also be seen in a more subtle form in absence seizures, or postictally in a variety of seizure types.

Spitting and drinking automatisms suggest right temporal localization.

Automatisms with preserved responsiveness also favor right temporal localization.

Extremity automatisms are less specific and can be seen in temporal as well as extratemporal epilepsy. However, the progression of these automatisms is more gradual in

temporal lobe epilepsy. In extratemporal epilepsy, they tend to have an abrupt bilateral onset and a frenzied character. The most common upper extremity automatisms are manipulative, involving interaction with the environment, for example picking on clothing or bedsheets or fumbling with objects. Manipulative automatisms in of themselves have no lateralizing value. However, the extremity contralateral to the side of the focus is often involved in dystonic posturing or immobility and may therefore not demonstrate automatisms. In this instance, manipulative automatisms will predominate in the extremity ipsilateral to the seizure focus. This may lead to confusion for the inexperienced observer, who may interpret repetitive automatisms as clonic activity. The less common non-manipulative upper extremity automatisms involve rhythmic repetitive motions that are either distal (milking, pill rolling, grasping, fist clenching, or opening–closing motions) or proximal (often with a circulatory character like waving or stirring). These automatisms tend to be contralateral and often precede dystonic posturing (Lee et al., 2006; Kelemen et al., 2010).

Seizures originating in the temporal pole often manifest with hypermotor activity, similar to what is seen in orbitofrontal complex partial seizures. This is related to seizure spread to the orbitofrontal region (Wang et al., 2008; Vaugier et al., 2009).

Defined in the strictest manner, dystonic posturing is an unnatural position that includes a rotatory component. Dystonic posturing has been associated with ictal activation in the contralateral putamen. There is evidence that there is a spectrum of posturing, with classical dystonic posturing at one extreme, and simple immobility of an extremity at the other, including subtle posturing without a clear demonstrated rotatory component in between. Dystonic posturing has a strong lateralizing value in temporal lobe epilepsy. However, as with any other manifestations, late occurrence could represent activation of the contralateral side and may therefore have a lesser value.

Head turning in temporal lobe epilepsy has been the subject of great controversy. Current evidence suggests that early head turning, particularly that associated with dystonic posturing, tends to be ipsilateral to the focus. Its mechanism is not well defined. Some have suggested it could represent neglect of the contralateral hemisphere. However, in many instances the early head turning is of a tonic nature, which raises the possibility of a motor drive, possibly from the basal ganglia. In one study, the occurrence of head turning within 30 seconds of seizure onset, in association with dystonic posturing and not leading to secondarily generalization, has been strictly ipsilateral to the temporal seizure focus (Fakhoury and Abou-Khalil, 1995). Late head turning, on the other hand, is more likely to be contralateral. Head turning that leads to secondary generalization can have a tonic or clonic character and has been termed "versive" or "adversive". Versive head turning is almost always contralateral to the seizure focus. However, an ipsilateral versive head turn has been noted towards the end of secondarily generalized tonic-clonic seizures in some patients (Wyllie et al., 1986).

Language Manifestations

Language manifestations are potentially very valuable in lateralizing temporal lobe seizure origin (Gabr et al., 1989).

Ictal speech arrest does not seem to have lateralizing value. It may be due to disruption of language mechanisms, to loss of awareness/responsiveness, or to a positive or negative motor effect. There is a suggestion, however, that in temporal simple partial seizures a speech arrest could represent aphasia and may thus be lateralizing to the dominant temporal lobe.

Well-formed ictal language strongly suggests a non-dominant right temporal lobe focus. This is not true, however, of single words or non-verbal vocalizations. The well-formed ictal language in some patients with right temporal lobe seizures has a tinge of fear. For example, it is not uncommon for patients to utter "I'm sick, I'm sick," or "I'm going to die, don't let me die." In most instances, however, the patient does not remember these utterances, and fear may not be a known component of the semiology.

Ictal jargon is rare but has been associated with dominant temporal lobe foci. It may reflect a partial disruption of language mechanisms, as seen in chronic Wernicke's aphasia.

Global aphasia may occur in association with localized simple partial seizures restricted in the temporal lobe, including the basal temporal language area. Chronic temporal lobe lesions do not produce global aphasia. However, acute electrical stimulation of Wernicke's area and basal temporal language area does produce global aphasia, perhaps because compensatory mechanisms have not had the chance to be activated. Global aphasia in simple partial seizures therefore could be consistent with a temporal localization.

Postictal aphasia is strongly associated with a left dominant temporal localization. In one study, all patients with right temporal seizures were able to correctly read a test sentence within one minute of seizure termination, while patients with dominant left temporal foci had disruption of reading for more than one minute. In patients with atypical language representation, the lateralizing significance of language dysfunction has to be reinterpreted.

Other manifestations

A variety of other ictal manifestations may have lateralizing value:

- Ictal vomiting has been associated with right-sided foci. However, this is not uniform, and vomiting may also be a manifestation of extratemporal foci.
- Ictal spitting, ictal flatulence, and ictal drinking are more common with right temporal foci.
- Unilateral eye blinking tends to be ipsilateral to seizure origin. Ictal vocalization has limited specificity with respect to localization or lateralization.
- Focal facial motor activity early in the seizure favors a lateral neocortical origin (Foldvary et al, 1997).
- Transition to secondary generalization. The motor manifestations during transition to secondary generalization can be very valuable in lateralization. Versive head turning, tonic posturing, and clonic activity are most often contralateral to seizure origin. Occasionally, however, they can be falsely lateralizing if there is contralateral seizure spread prior to generalization.

Postictal manifestations:

- Postictal cough has been found predominantly following right temporal seizures.
- Postictal nose wiping tends to be performed with the hand ipsilateral to the seizure focus.
- Postictal urinary urgency suggests a right temporal localization.

None of the above signs is sufficient in isolation. However, the combination of several signs and symptoms can be a powerful tool in localizing and lateralizing temporal lobe epilepsy. The addition of semiological information unquestionably enhances the localizing ability of the presurgical evaluation.

Parietal

The parietal lobe is the next most likely source of seizures after the temporal and frontal lobe.

Aura: The best recognized manifestation of parietal lobe origin is a sensory aura, particularly if there is an associated march. The sensation can be described as numbness, tingling, pins and needles, burning, or pain. It can also be nondescript.

Sensory march is strongly suggestive of a post-central, primary sensory cortex involvement. This is lateralized contralaterally to the ictal discharge.

Sensory aura without march can originate in the second sensory area, which is located over the parietal operculum. The sensory manifestations from the second sensory area are most often contralateral, but they are occasionally ipsilateral or bilateral.

Vertigo, difficulty localizing body position in space, sensation that a body part is moving, or that an extremity is absent are other less common sensory auras that suggest a parietal lobe origin.

Focal weakness has also been described with parietal foci. Seizures with focal weakness have been referred to as focal inhibitory motor seizures or focal atonic seizures (Abou-Khalil et al., 1995). They frequently have a preceding sensory aura.

Seizures without parietal lobe symptoms: Most patients with parietal lobe epilepsy have no parietal lobe symptoms, but rather manifestations resulting from spread to occipital, temporal, or frontal lobe.

Common manifestations with frontal lobe propagation include:

- Contralateral tonic posturing;
- Focal clonic activity;
- Generalized asymmetrical tonic posturing;
- Head and eye deviation, described in almost 50% of patients.

When there is propagation to the temporal lobe, complex partial seizures can be characterized by:

- Staring;
- Relative immobility with minimal automatisms;
- Oro-alimentary automatisms.

Occipital

Aura: Sensory symptoms suggesting occipital origin are:

- Visual aura is the key manifestation that suggests occipital lobe origin.
- Elementary visual hallucinations strongly suggest involvement of primary visual cortex. These hallucinations may be black or white or colored. They can be flashing or steady. They can be stationary or moving. There may be distortion of vision, and there may also be a loss of vision. The ictal blindness can be a blackout or a whiteout. If this is in one field, it strongly suggests seizure activity contralateral to that field. More complex visual hallucinations, such as ones involving scenes, suggest involvement of the occipitotemporal junction.
- Auditory hallucinations, vertigo, and focal sensory experiences may also be seen, but suggest seizure spread to the lateral temporal or parietal regions.

Motor symptoms suggesting occipital origin include:

- Bilateral blinking;
- Nystagmoid eye movements;
- Eye deviation, usually contralateral.

One distinctive feature of occipital lobe seizures that develop and propagate posteriorly is the slow progression of ictal manifestations. For example, the eye deviation that is seen with occipital lobe origin tends to be much slower than that noted with frontal lobe origin.

Some studies suggest that manifestations of seizures originating in the occipital lobe are most commonly related to seizure spread to the temporal or frontal lobe. Seizure spread to the temporal lobe commonly manifests with oroalimentary automatisms, while seizure spread to the frontal lobe may produce asymmetrical tonic posturing. Secondary generalization is common with frontal lobe propagation.

Insular

Insular epilepsy cannot be analyzed with scalp video EEG studies since it is not possible to record from the insula with scalp electrodes. The semiology of insular epilepsy was elucidated only with analysis of seizures recorded with depth electrodes implanted in the insula (Isnard et al., 2004).

Aura: The most common subjective manifestations of seizure activity in the insula are laryngeal discomfort, shortness of breath, and paresthesias around the mouth. Sensory manifestations may also involve other body parts contralaterally. Autonomic manifestations are common, with visceral sensations in the chest or abdomen.

Motor: Dysarthria or dysphonia may occur, at times extreme with resultant muteness. Hypersalivation is very common. Seizure propagation to the frontal lobe may manifest with tonic spasm of the contralateral face and upper extremity, and contralateral head and eye deviation. There may be hypermotor manifestations mimicking frontal lobe complex partial seizures (Ryvlin et al, 2006). There may also be typical temporal semiology with spread to the temporal lobe.

Other

Seizures very rarely start in subcortical regions. The best recognized are hypothalamic seizures from *hypothalamic hamartomas*. The most typical seizure type is gelastic seizures (seizures with laughter), and some of these patients may also have dacrystic seizures (seizures with crying). However, patients with hypothalamic hamartomas may also have other seizure types that seem to develop over time, including complex partial seizures, non-gelastic simple partial seizures, generalized tonic-clonic seizures, and some other generalized seizure types, such as atonic and tonic seizures and epileptic spasms.

There are also rare reports of seizures starting in cerebellar gangliogliomas, usually in infants (Harvey et al, 1996; Chae et al., 2001). These seizures are characterized by hemifacial twitching ipsilateral to the lesion, and at times contralateral head and eye deviation or contralateral nystagmus.

Generalized

Generalized-onset seizures start simultaneously in both hemispheres. They vary considerably in severity of clinical manifestations (see Table 5-2). At one extreme are generalized tonic-clonic seizures, and at the other are generalized absence seizures. The reason that generalized absence seizures are generalized yet so mild in clinical manifestations is that they involve a restricted bilateral frontoreticular network.

Table 5-2 Semiology of Generalized Seizures

Seizure type	***Semiology***
Generalized absence	Sudden behavior arrest and loss of awareness. Simple automatisms; subtle twitching or change in tone.
Atypical absence	Sudden loss of awareness but with slower recovery and more prominent motor symptoms such as myoclonic, tonic or atonic components.
Generalized absence with eyelid myoclonia	Eyelid myoclonia occurs in addition to absence symptomatology
Myoclonic absence	Absence but with prominent myoclonic activity at the same frequency as the spike-and-wave discharge.
Myoclonic seizures	Brief myoclonic jerks (fraction of a second) too short for clear alteration in consciousness
Generalized tonic-clonic seizures	Initial tonic phase followed by clonic phase with prominent postictal period.
Generalized tonic seizures	Sudden loss of consciousness with generalized tonic posturing. Usually in neurologically impaired individuals.
Generalized atonic seizures	Sudden loss of tone either restricted (e.g., head) or whole body. One cause of drop attacks.
Epileptic spasms	Sudden flexion (or extension) of trunk with arm abduction
Myoclonic-atonic seizures	Myoclonic jerk precedes the atonic phase.
Negative epileptic myoclonus	Loss of tone for a fraction of a second without disturbance of consciousness.

Generalized Absence Seizures

These seizures can occur in a variety of epileptic syndromes, particularly childhood absence epilepsy and juvenile absence epilepsy (Hirsch and Panayiotopoulos, 2005). These seizures are characterized by sudden onset without any aura, brief duration, typically less than 15 seconds, and sudden termination without any postictal state. Typical generalized absence seizures are associated with generalized 2.5–4 Hz spike-and-wave activity (see Figure **5-2**).

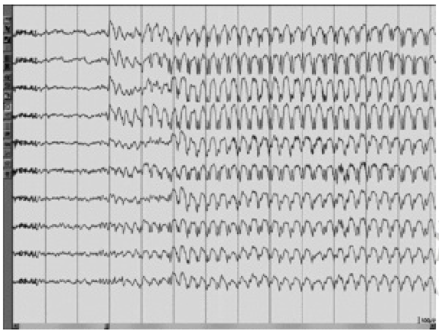

Figure 5-2:

Typically, there is suspension of awareness and arrest of activity during the episodes, but some motor manifestations are quite common. Absence seizures with altered awareness or responsiveness only are sometimes called *simple absence seizures*. When there is associated motor activity or autonomic manifestations, absence seizures are sometimes referred to as *complex absence seizures* (to be distinguished from *complex partial seizures*).

Simple automatisms are the most common, particularly perseverative automatisms. Automatisms may include fumbling with an object that the patient was holding, rubbing a body part, or mouth movements such as licking lips. Automatisms are more likely with longer duration of absence seizure activity.

Myoclonus is the next most common motor manifestation. This includes blinking and subtle twitching of fingers.

Tonic features may occur, with up-rolling of the eyes and slight stiffening of the neck with neck extension, though this is mild.

Atonic components can also be seen, with slight decrease of tone and slumping, again to a mild degree.

Autonomic manifestations may occur, including pupillary dilation, piloerection, and infrequently, incontinence. At times, consciousness is partially preserved. This is more likely to occur in adults who have had persistent absence seizures from childhood.

When there is some preservation of awareness but loss of responsiveness, patients may describe some subjective experiences that could erroneously suggest an aura. For example, lightheadedness or spaciness may be reported. In addition, some patients report confusion after the seizure. This usually reflects the effect of missing parts of a conversation rather than true confusion.

Atypical Absence Seizures

This variant of generalized absence seizures tends to occur in symptomatic generalized epilepsy, such as Lennox-Gastaut syndrome. The main distinction between typical and atypical absence seizures is electrographic, as the latter have a slower frequency of less than 2.5 Hz (see Figure **5-3**). Clinical distinctive features reported are a slower loss of awareness and a more gradual recovery, as well as perhaps more prominent motor manifestations.

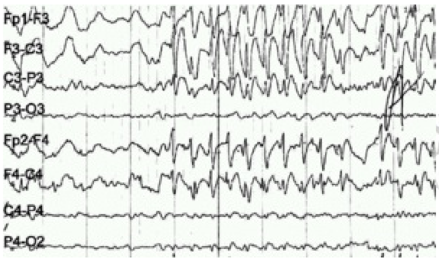

Figure 5-3:

Generalized Absence Seizures with Eyelid Myoclonia

These seizures occur predominantly in women, as part of an epileptic syndrome. In this syndrome, eyelid myoclonia may occur with or without associated spike-and-wave activity (Caraballo et al., 2009). Women with this condition are usually photosensitive and also have eye closure sensitivity.

Myoclonic Absences

These seizures associated with the typical 2.5–3.5 Hz spike-and-wave discharge differ from absence seizures by the presence of a very prominent clonic activity at the same frequency as the spike-and-wave discharges. The seizures in this syndrome tend to be harder to control.

Generalized Myoclonic Seizures

Generalized myoclonic seizures last a fraction of a second (see Figure **5-4**). They vary in severity from mild with barely visible twitch to severe with massive myoclonus associated with falling. The myoclonic jerk may involve the whole body, or the upper extremities or the head alone. Although they are usually bilateral, they could be unilateral with shifting lateralization. Myoclonic seizures are not associated with loss of consciousness because of their very brief duration. They often occur in clusters, and patients occasionally report some disruption of consciousness with a cluster of closely spaced seizures.

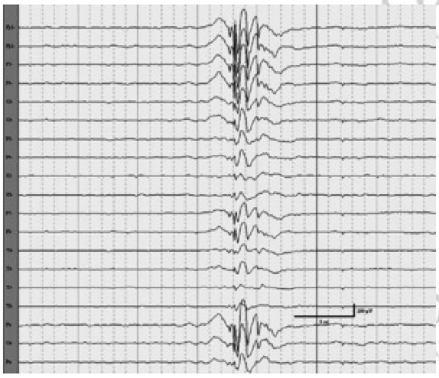

Figure 5-4:
The reference is linked ears.

Generalized myoclonic seizures are to be distinguished from non-epileptic myoclonus, which can originate at any level of the central nervous system.

Generalized Clonic Seizures

These seizures, characterized by rhythmic clonic jerking, start with loss of consciousness. They are infrequent. They are seen in children with severe myoclonic epilepsy of infancy (Dravet syndrome) and patients with progressive myoclonic epilepsies.

Generalized Tonic-Clonic Seizures

Generalized-onset tonic-clonic seizures do not have an aura, although they may be preceded by a prodrome (sometimes prolonged feeling of being seizure-prone). The onset is abrupt, with loss of consciousness, then generalized tonic contraction. In patients with juvenile myoclonic epilepsy, it is common for generalized tonic-clonic seizures to start with repetitive myoclonic jerks (then called *clonic-tonic-clonic seizures*). Generalized tonic-clonic seizures may also evolve from generalized absence seizures. The tonic phase may be symmetrical, but asymmetries may be seen. In particular, versive head turning is common, and may change direction from one seizure to the other. Versive head turning alone does not mean that the seizure onset was focal (Niaz et al, 1999; Chin and Miller, 2004). The tonic phase may show evolution from flexion to extension. The eyes are usually half open and the mouth is open. A loud vocalization may result from contraction of the diaphragm and contracted glottis. Cyanosis is most likely to occur during the tonic phase of the seizure. Clonic activity evolves from the tonic phase, initially with high frequency, but progressing to lower frequency and larger amplitude. After the jerking stops, the individual is limp and unresponsive, with stertorous respiration. Postictal confusion and sleep are common. The postictal manifestations are similar to what is noted with secondarily generalized seizures. See Figures **5-5a** through **5-5d** for the EEG appearance of a generalized tonic-clonic seizure.

Figure 5-5a:

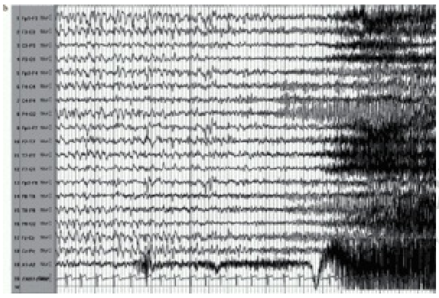

Figure 5-5b:

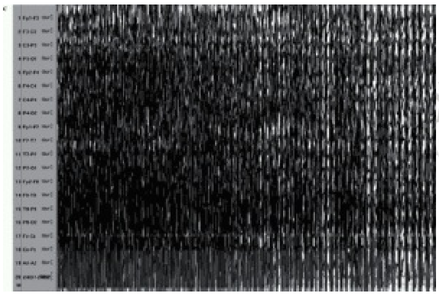

Figure 5-5c:

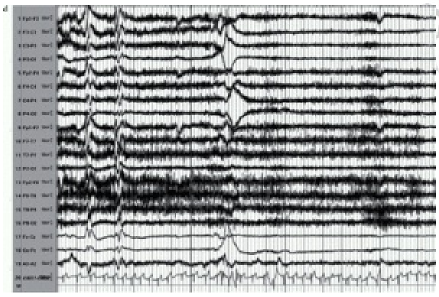

Figure 5-5d:

The duration of the postictal period can be from minutes to hours; however, a postictal period of days is not expected and other pathology has to be considered. Prolonged generalized tonic-clonic seizures, even if masked by paralytics, can cause neuronal damage, so failure to improve following a prolonged seizure can be of concern for sustained damage.

Generalized Tonic Seizures

These seizures occur most often in neurologically impaired individuals. They are more likely to occur out of sleep. They are characterized by sudden loss of consciousness with generalized tonic posturing that may be asymmetric, with turning to one side. The pattern of muscle involvement may evolve, producing a change in body and limb position over the course of the seizure. The tonic contraction may end with one or more pauses that result in a few clonic jerks. The posturing/stiffening can be generalized and massive or minimal, manifesting only with eye opening or with slight neck extension.

Tonic seizures can be abrupt or can manifest with slow posturing. The most common pattern of generalized tonic seizure posturing involves flexion of the trunk and extension of the extremities with abduction at the shoulders. There may be associated vocalization, particularly with the massive and abrupt generalized tonic seizures.

Generalized tonic seizures are typically quite brief but may have a postictal state with a duration and severity that are disproportionate to their duration. This may be because tonic seizures may be followed by atypical absence, referred to as *tonic-absence seizures* (Shih and Hirsch, 2003).

These seizures can be difficult to distinguish from partial-onset seizures of frontal or parietal origin.

Epileptic Spasms

Epileptic spasms is the term now recommended to replace *infantile spasms*, because these seizures may occur after infancy (Goldstein and Slomski, 2008; Ramgopal et al., 2012). Epileptic spasms are shorter than generalized tonic seizures but longer than generalized myoclonic seizures. The intensity of contraction is greater in the middle of the spasm than at onset or termination, while the contraction seen with tonic seizures is more likely to be sustained. The classic epileptic spasm involves flexion of the neck and trunk with arm abduction. These seizures typically occur in clusters, with a seizure every few seconds to a minute, and demonstrate increasing then decreasing intensity over the course of the cluster.

Generalized Atonic Seizures

These seizures can vary in manifestation from subtle drooping of the head to a massive loss of tone with falling. They are more common in children. They are associated with drop attacks. Drop attacks can be due to tonic seizures as well, and the distinction of the two can be difficult without direct observation.

Generalized atonic seizures are associated with brief loss of consciousness. The duration is usually not more than a few seconds. More prolonged atonic seizures are seen in association with Lennox-Gastaut syndrome and related epilepsies.

Myoclonic-Atonic Seizures

These seizures are commonly part of the syndrome of myoclonic astatic epilepsy, also referred to as Doose's syndrome. In these seizures, a myoclonic jerk precedes the loss of tone. The seizures are very brief with rapid recovery. However, injuries are not uncommon with a fall from loss of tone.

Negative Epileptic Myoclonus

Just as asterixis resembles non-epileptic myoclonus, but with momentary loss of tone rather than momentary contraction, negative epileptic myoclonus is associated with very brief loss of tone that may not be appreciated unless the affected extremities are elevated or engaged in other activity.

Generalized-Onset Seizures with Focal Evolution

Just as focal onset seizures may secondarily generalize, generalized-onset seizures rarely evolve to become focal (Williamson et al., 2009). This focal evolution can occur with generalized myoclonic or generalized absence seizures. Such seizures most often manifest with prolonged staring and arrest of activity, at times with subtle automatisms. Focal clonic activity may also occur. Postictal confusion is common and results in misdiagnosis as complex partial seizures.

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Differential Diagnosis

Chapter: Differential Diagnosis
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Overview

The differential diagnosis of seizures includes a host of non-epileptic events. The most common conditions in the differential diagnosis vary somewhat with age. For example, transient ischemic attacks (TIAs) and transient global amnesia are important conditions in the differential diagnosis in old age, but not in younger individuals. Psychogenic nonepileptic seizures, syncope, and some sleep disorders imitate epilepsy through much of the lifespan. Most of these are nonepileptic neurologic, cardiac, vascular, or psychiatric in origin.

Table 6-1 lists some common disorders that can be mistaken for seizures.

Table 6-1 Disorders Often Mistaken for Seizures	
Disorder	***Features***
Psychogenic non-epileptic seizure	Psychogenic event that resembles a clinical seizure but is not due to abnormal electrical discharge and not associated with ictal abnormalities on EEG. Psychological disorder.
Syncope	Episodic loss of consciousness due to hypo-perfusion of the brain. Wide variety of causes including arrhythmia, vasovagal syncope, orthostasis.
Breath-holding spells	Children may hold their breath until they lose consciousness. Subsets include pallid and cyanotic breath-holding spells.
Cough syncope	Loss of consciousness associated with decreased cerebral perfusion. Most often seen in individuals with COPD, asthma, or other causes of chronic cough.
Sleep myoclonus	Periodic jerks of the extremities during sleep. Interferes with quality of sleep.
Parasomnia	Include night terrors, sleep walking, and some cases of nocturnal bed-wetting. Can be mistaken for seizure or postictal effect.
Chorea	Irregular stereotypic movements of the extremities. Due to disorder of the basal ganglia.
Sandifer syndrome (reflux)	Torsional dystonia mainly involving the neck and shoulders. Associated with hiatal hernia and esophageal reflux.
Non-epileptic myoclonus	Myoclonus during the day but not associated with EEG changes.
Startle	Startle-induced seizures can be seen in patients with certain types of epilepsy, but excessive startle alone is usually not epileptic
Transient peak toxicity and drug-induced encephalopathy	Patients taking AEDs may misinterpret symptoms of peak level toxicity as seizures. The key distinguishing features are duration (usually longer than 10 minutes), type of manifestations, and relationship to AED intake. Tiagabine may be associated with prolonged episodes of altered awareness and responsiveness which may be a type of encephalopathy or tagabine-induced absence status epilepticus.
Transient ischemic attacks	Usually present with episodic loss of function due to focal ischemia
Transient global amnesia	Episodes of memory loss without other cognitive disturbance
Panic attacks	These can resemble some seizure manifestations of temporal lobe epilepsy
Behavioral abnormalities in children and adults with mental retardation	Repetitive movements in children with mental retardation. Can resemble seizure activity because of repetitive stereotypic movements.
Rage attacks and violence	Rage attacks and directed violence are almost never epileptic. Non-directed violence can be epileptic, but usually is not.

Psychogenic Nonepileptic Seizures (PNES)

PNES are emotionally-triggered attacks that resemble seizures, but are not associated with epileptic seizure activity. Approximately 20% of patients presenting to an epilepsy center with intractable epilepsy are found to have nonepileptic seizures. The term *nonepileptic seizures* is preferable to the term *pseudoseizures*. *Psychogenic nonepileptic seizures (PNES) or Psychogenic nonepileptic events* is even more specific, since the term *nonepileptic seizures* could potentially include other disorders for which this term is certainly not intended. The incidence of PNES in the general population can reach up to 5 per 100,000 persons per year. There is a higher prevalence in women who represent 70-80% of those affected.

Some patients have both epileptic seizures and nonepileptic seizures, perhaps 10-15% of patients with PNES (Benbadis et al., 2001; Lesser et al., 1983; Martin et al., 2003). Distinguishing the two can be difficult. We often have to teach the patient or family how to distinguish the two and ask for the frequency of each type of event separately.

Clinical Presentations

A major role of epilepsy monitoring units is the differentiation of epileptic seizures from PNES, and video-EEG monitoring has helped analyze the semiology of nonepileptic seizures. The spectrum of clinical presentations of non-epileptic seizures is almost as broad as that of epileptic seizures. PNES semiology can be classified in three categories: PNES with generalized shaking, PNES with minor motor activity, PNES with motionless unresponsiveness or collapse (Groppel et al., 2000; Meierkord et al., 1991; Selwa et al., 2000). Generalized shaking is the most common manifestation of PNES in adults and adolescents. Staring spells can occur as well, with clinical features that could be mistaken for absence or complex partial seizures. In children, prolonged staring and unresponsiveness was the most common pattern (Kramer et al., 1995). Although there are many features that PNES have in common with epileptic seizures, there are some differentiating features (Szabó et al., 2012; DeToledo and Ramsay, 1996; Gates et al., 1985; Avbersek and Sisodiya, 2010; Chung et al., 2006; Azar et al., 2008).

Clinical features that may suggest PNES as opposed to generalized tonic-clonic seizure include:

- Responsiveness during a generalized convulsive seizure;
- Seizure usually precipitated by suggestion;
- Forward pelvic thrusting;
- Large amplitude side-to-side head movements.
- Asynchronous or alternating jerking of the two sides (as opposed to synchronous jerking);
- Absence of whole-body rigidity before generalized jerking.
- Seizure can be terminated by the examiner by non-pharmacological means such as suggestion
- Abrupt termination of the seizure, without a postictal period;
- Eyes closed during an event, particularly if there is reistance to eye opening (DeToledo and Ramsay, 1996).
- Shallow rapid respiration (as opposed to stertorous respiration)

No single clinical feature is sufficient for diagnosis; combination of features increases their value. Many of the above clinical features are reported in frontal lobe complex partial seizures; PNES tend to be prolonged in duration, while frontal complex partial seizures are short in duration (Saygi et al., 1992).

PNES usually do not start out of sleep. Seizures that clearly arise out of sleep are usually epileptic. However, PNES may arise out of a waking state by EEG while the patient clinically appears asleep (pseudosleep).

Other features that favor PNES include:

- Discontinuous clinical seizure activity.
- Prolonged seizure duration (pseudostatus epilepticus is common in patients with PNES)
- Eye fluttering
- Dramatic vocalizations of choking, gagging or gasping
- Stuttering
- Weeping and other emotional display
- Excessive variability in seizure manifestations

Despite these general guidelines, experienced neurophysiologists are commonly wrong in clinical diagnosis of seizures because of the broad spectrum of how epileptic seizures and nonepileptic seizures can manifest. Vagal nerve stimulation (VNS) has even been placed in patients in whom PNES was ultimately documented (Arain et al., 2011). Video-EEG monitoring with recording of typical attacks is crucial for the definitive diagnosis of PNES.

Suggestion may help trigger PNES; hyperventilation and photic stimulation are preferred suggestion techniques, since they are usually standard for all patients. If other suggestion methods are used, they should not involve patient deception. It is also important to keep in mind that some individuals are suggestible and suggestion may precipitate atypical events. Family members have to view the recorded events and verify that they are typical for recorded attacks.

It is important to keep in mind that some epileptic seizures may have no scalp EEG correlate; examples include cingulate or orbitofrontal complex partial seizures, supplementary motor seizures, and motor simple partial seizures. It is often necessary to record multiple attacks to evaluate if events are stereotyped. Frontal lobe seizures tend to be very stereotyped. In addition, they may demonstrate increased severity in association with AED withdrawal. Secondary generalization is usually definitive proof that the initial manifestations are epileptic.

Urinary incontinence has been considered by some to be a differentiating feature between epileptic and non-epileptic events, but this is not the case if one depends on history; urinary incontinence has no significant differentiating value between epileptic, nonepileptic, and syncopal events (Brigo et al., 2013; Peguero et al., 1995).

Tongue biting occurs more commonly with epileptic generalized tonic-clonic seizures, but is also frequently reported by patients with PNES (Peguero et al., 1995). Epileptic seizures are associated with biting the side of the tongue, while PNES are more likely to be associated with biting the tip of the tongue or the lip (DeToledo and Ramsay, 1996).

EEG Manifestations

EEG during nonepileptic seizure is normal, although muscle and movement artifact may obscure the recording. Evaluation of the recording may depend on observing the EEG background immediately before and after the clinical seizure. Epileptic seizures have a slow and/or suppressed background after the seizure, whereas non-epileptic seizure shows an EEG background that returns to normal immediately after the seizure artifact subsides (see Figure **6-1**).

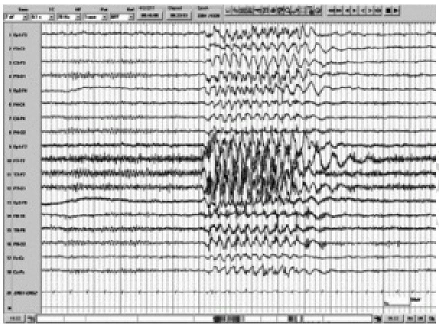

Figure 6-1:
Top shows baseline EEG, Bottom shows EEG during non-epileptic seizure.

This patient shows movement and muscle artifact, but there is no electrocerebral discharge associated with the clinical seizure activity. Movement during an epileptic or non-epileptic seizure can obscure the EEG, so that visualization or non-visualization of electrographic seizure activity is not possible. The EEG activity immediately before and after the clinical seizure activity is evaluated to determine whether there is an abnormality that makes it more or less likely to be epileptic. This differentiation is described in Table 6-2 (see also Figures **6-2** and **6-3**).

Table 6-2 Differentiation of Epileptic from Non-epileptic Events		
Feature	***Epileptic event***	***Non-epileptic event***
EEG before event	May be normal or show focal or generalized discharges prior to the clinical seizure	Normal EEG
EEG during event	Electrocerebral discharge during the seizure	No electrocerebral discharge during the episode. Muscle and movement artifact may obscure the recording.
EEG after event	May show slowed activity or attenuation after the seizure	Normal, no postictal slowing or attenuation.

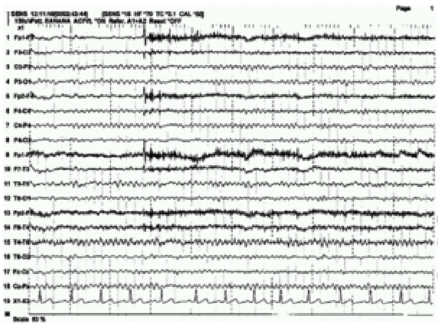

Figure 6-2:

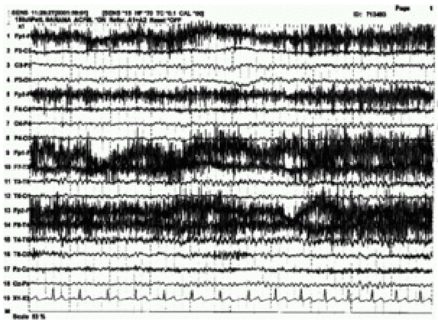

Figure 6-3:
Figure **6-2**).

Evolution of EEGs of Nonepileptic Seizure with Tremor

Figures **6-4** through **6-7** are the recordings of a 26-year-old female with recurrent psychogenic non-epileptic seizures. The rhythmic activity represents artifact due to rhythmic coarse tremor.

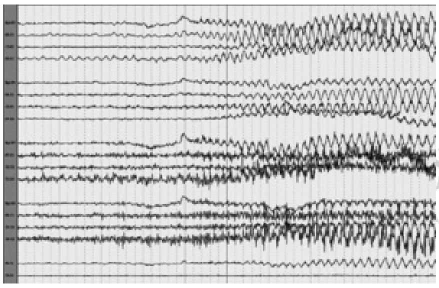

Figure 6-4:

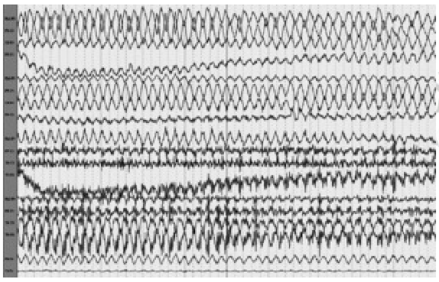

Figure 6-5:
Monorhythmic Electrical Activity with the Tremor.

The background is obscured.

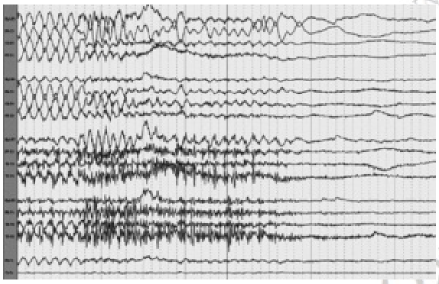

Figure 6-6:
Termination of the Clinical Seizure Activity.

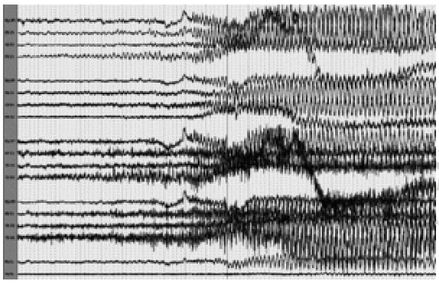

Figure 6-7:

Figure **6-4** shows rhythmic activity associated with clinical seizure activity, which could easily be confused with epileptiform activity. The normal background is replaced by growing artifact from movements. There are no spikes in association with the slow activity. In addition, the frequency does not evolve during the course of the activity.

The page shown in Figure **6-5** directly follows the page shown in Figure **6-4**. The repetitive slow activity continues at a constant frequency, without evolution in appearance of rhythm.

The last epoch of EEG (Figure **6-6**) shows the end of the seizure, where the amplitude of the activity reduces until normal background returns. There is not background slowing or attenuation, although reduction in amplitude results in appearance of attenuation, especially if gain was reduced during the episode. Termination of the seizure is associated with restoration of the normal background.

Observation of the same seizure at a slower time base (Figure **6-7**) shows the monorhythmic character of the clinical seizure, quite different from the appearance of an epileptic seizure.

Syncope

Overview

Episodic disturbance of consciousness includes not only seizure activity but also syncope. Syncope is transient loss of consciousness due to loss of brain perfusion, but the differential diagnosis of this final common path is wide.

Causes of Syncope

The causes of syncope are multiple, some of which include:

- Cardiac arrhythmia;
- Orthostatic hypotension;
- Vasovagal ("neurocardiogenic") syncope;
- Orthostatic hypotension;
- Migraine;
- Vertebrobasilar insufficiency.

Most causes of syncope are preceded by a sensation of light-headedness. However, the duration of this may not be long enough for it to be remembered. Syncope due to cardiac arrhythmia may also be more abrupt with no preceding lightheadedness. Among the cardiac causes are both brady- and tachy-arrhythmias. Orthostatic hypotension is characterized by light- headedness and syncope when the patient arises to a stand (Carreño, 2008; Crompton and Berkovic, 2009). Basilar migraine is commonly associated with dizziness that is more akin to true vertigo than presyncopal sensation. Migraine, in general, can be associated with syncope due to autonomic instability (Thijs et al., 2006) Likewise, vertebrobasilar insufficiency can be associated with syncope as a component of the symptoms, but dizziness and ataxia are more common symptoms.

Differentiation of Syncope from Seizure Activity

Differentiation of syncope from seizures is often a focus of neurologic consultation. While syncope is best recognized by loss of consciousness, loss of tone and loss of posture,

most individuals will have brief multifocal arrhythmic myoclonus, which is a common source of misdiagnosis of epileptic seizures (Lempert et al., 1994). Syncope with myoclonus has been called "convulsive syncope", but the myoclonus is of brainstem origin, not cortical in origin. In addition to myoclonus, patients with syncope may have posturing, head turning, lateral or upward eye deviation, or oral automatisms.

Some differentiating features are:

- Syncope can be triggered by certain activities, unexpected with seizures. Examples include intense pain, intense emotion, standing for prolonged periods of time in hot crowded places, sudden standing from sitting or lying position, urination, defecation, cough. In addition, presence of dehydration, known heart disease and prior syncope should favor syncope.
- Syncope often has warning presyncopal sensation, such as nausea, cold sweat, lightheadedness, graying of vision, sounds becoming more distant, different from common seizure auras.
- The myoclonus associated with syncope is of much shorter duration (usually less than 15 seconds) than tonic-clonic activity (usually longer than 15 seconds)
- Prominent pallor described by witnesses favors syncope although it may also be an autonomic manifestation of some seizures.
- Seizures result in postictal confusion or lethargy, not expected with syncope. However, if the fall from syncope results in concussion, there could be more confusion than expected.
- Recollection of loss of consciousness favors syncope (Crompton and Berkovic, 2009).

Breath-holding Spells

Breath-holding spells can be frightening to parents, and can be mistaken for seizures or even cardiac arrest. There are two types of breath-holding: cyanotic and pallid.

Cyanotic breath-holding spells are characterized by a brief cry, followed by apnea in end-expiration. The child becomes cyanotic and unconscious because of hypoxia. A few minutes later, the child awakens.

Pallid breath-holding spells are characterized by little or no cry, followed by asystole, resulting in the pallid appearance. The child is pale and lifeless. The child becomes awake and normal color in minutes.

Diagnosis of breath-holding spells depends on observation, and the spells can be frightening, even to experienced clinicians. EEG can help differentiation. In both types of spells, the EEG becomes suppressed and, depending on duration, virtually flat.

Cough Syncope

During prolonged coughing, intrathoracic and intra-abdominal pressures are transmitted via the great veins to the intracranial compartment, causing transient elevated intracranial pressure. The resulting reduction of cerebral perfusion pressure may cause a critical impairment of cerebral blood flow (CBF).

During coughing, patients show a transient cerebral circulatory arrest, which coincides with loss of consciousness. EEG shows slowing and attenuation (see Figure **6-8**).

Figure 6-8:

Obstructive airway disease seems to be a prerequisite to build up the intrathoracic and intracranial pressures to a degree sufficient to compromise CBF and cause cough syncope.

Other Disorders Mistaken for Seizures

Movement Disorders

Some movement disorders can have sufficient fast components that they might be confused with seizure activity. This is especially true for myoclonus but also for others including dyskinesias and hemiballismus.

Nonepileptic Myoclonus

Myoclonic seizures, seen in a number of epileptic syndromes, particularly juvenile myoclonic epilepsy (JME), are generated in the cortex, and usually associated with an electrical discharge at the scalp. However, myoclonus can also be nonepileptic, and can be generated at any level of the central nervous system. Essential myoclonus is episodic jerking not associated with other epileptic or degenerative disease. There are either no other neurologic signs, or there may be dystonia or tremor. Inheritance can be dominant or sporadic. The dominant essential myoclonus usually presents before the age of 20 years. The movements disappear in sleep. Treatment of benign myoclonus is usually not needed.

Nocturnal Myoclonus

Nocturnal myoclonus is a normal phenomenon. However, if excessive, it may interfere with the quality of sleep.

Nocturnal myoclonus is commonly seen as a primary disorder or with restless legs syndrome (RLS), but can also be secondary to a variety of other medical and neurologic conditions.

Chorea and paroxysmal dyskinesia

Chorea can occasionally be confused with seizure activity because of repetitive and stereotyped writhing, twisting movements.

Differentiation of chorea from seizure is aided by the following features:

- Chorea is associated with maintained ability to move the limbs, even during the episode of involuntary limb movement.
- Chorea is present only in the waking state and disappears during sleep.
- Chorea is not associated with postictal weakness.
- Chorea is not associated with cognitive changes.

When chorea is paroxysmal, it is more likely to be confused as epileptic. Paroxysmal dyskinesia is characterized by combinations of chorea, athetosis, ballism, and a dystonic posture, occurring in attacks. It is classified into two broad categories: kinesigenic and non-kinesigenic (Fahn and Frucht, 2008). Both conditions are usually familial.

Kinesigenic dyskinesia: The attacks of paroxysmal kinesigenic dyskinesia are very brief, lasting seconds, and are brought on by a sudden movement, particularly after inactivity. The movements may or may not be stereotyped, and can be bilateral or alternate sides. This is helpful in distinguishing them from epileptic seizures which tend to consistently affect the same side. As with other movement disorders, consciousness is always preserved, and there is no postictal change. However, the condition responds very well to antiepileptic drugs which are effective in preventing recurrence of attacks.

Nonkinesigenic dyskinesia: The attacks in paroxysmal nonkinesigenic dyskinesia are longer, lasting minutes to hours. They are not precipitated by movement, but can be brought on by a variety of factors such as stress, fatigue, excitement, alcohol, or caffeine. This condition does not usually respond to antiepileptic drugs.

Hemiballismus

Hemiballismus is violent movements of one side of the body. The movements are most marked in the proximal muscles. The flailing of the limbs can result in injury to the patient.

Hemiballismus is due to damage to the subthalamic nucleus, with stroke being the most common cause.

Hemiballismus can be mistaken for seizure activity, but can be differentiated by preservation of consciousness and movement of the affected side, normal EEG during the movement, and irregular appearance of the movements.

Hyperekplexia

Hyperekplexia is characterized by exaggeration of startle reflexes (Crompton and Berkovic, 2009). The exaggerated startle can be mistaken for a startle-evoked seizure. Hyperekplexia is an inherited disorder, most often with an autosomal dominant transmission.

Paroxysmal nocturnal dystonia

Paroxysmal nocturnal dystonia is episodic abnormal movements and postures in sleep. These were thought to be a movement disorder as they were not associated with scalp EEG changes. However, investigation with intracranial electrodes has indicated that these are indeed mesial frontal seizures.

Sleep disorders

Parasomnias

Parasomnias are disorders of sleep characterized by “undesirable physical events or experiences that occur during entry into sleep, within sleep, or during arousals from sleep”. [Thorpy, 2012; American Academy of Sleep Medicine, 2005.] They can be subdivided into disorders of arousal from non-REM sleep, parasomnias associated with REM sleep, and other parasomnias. (see Table 6-3).

Table 6-3 Sleep disorders that could be mistaken for seizures.

Disorder	***Features***
Restless legs syndrome	Motor restlessness associated with discomfort or pain and urge to move.
Sleep myoclonus	Jerking of the legs, which can cause arousal. Differentiated from seizure in part by occurrence of single jerk and arousal.
Hypnic jerks	Brief jerks at sleep inception. Differentiated from seizures in part because they are single jerks and not seen in deep sleep.
Rhythmic movement disorder	Rocking of the head or body, especially in young children, often misinterpreted as seizure activity. Head banging is the most common type.
Sleep walking	Occasionally confused with seizure because the patient may appear confused as if postictal.
Sleep talking	Seldom confused with seizures in the absence of other symptoms.
Sleep terrors and nightmares	Abrupt awakening with fright; sleep terrors are from non-REM sleep, nightmares are from REM sleep.
REM behavior disorder	Motor activity during dreaming can be vigorous and even violent, but differs from stereotyped movements of nocturnal seizures.
Enuresis	Losing control of bladder at night can suggest seizure, but this would seldom be the only sign.

In general, parasomnias tend to occur in younger patients, children and young adults. Some have a familial basis. Parasomnias can be mistaken for seizures, particularly frontal lobe seizures which often arise out of sleep. Differentiation depends on careful history and observation. Video EEG monitoring can aid in the differential diagnosis, although this is seldom needed.

Arousal parasomnias: Sleep walking, sleep terror, and confusional arousals are arousal parasomnias that occur with partial awakening out of slow wave sleep, the deepest non-REM sleep, usually within 1 to 3 hours after sleep onset. With all arousal parasomnias, the child usually has no memory of the events. These parasomnias cause concern

in family members. With sleep walking, patients are found to be walking around or standing. The eyes are open and there may be partial responsiveness. When the patient is stimulated, arousal is often accompanied by confusion and disorientation for a brief time. With confusional arousals the child may be found seated in bed with eyes open, appearing alert, but unresponsive. Again, if awakened, the child will be confused and frightened. Sleep terrors have more extreme manifestations, with screaming, crying, facial expression of terror, agitation, and thrashing. There is often associated sweating, tachycardia and tachypnea. The duration is a few minutes, and the patient then goes back to sleep. Sleep terrors are more common in children, and become less prevalent with increasing age.

The distinction between arousal parasomnias and nocturnal frontal lobe seizures is based on the following clinical features (Tinuper et al., 2012):

- Arousal parasomnias tend to have an earlier age at onset than nocturnal frontal lobe seizures, and tend to resolve with increasing age, unlike frontal lobe seizures.
- Arousal parasomnias typically occur once in a night, infrequently, while frontal lobe seizures are more frequent, often with several in one night.
- Arousal parasomnias last several minutes, while frontal lobe seizures usually last less than one minute.
- Episodes in arousal disorders can vary in clinical manifestations, while frontal lobe seizures are very stereotyped.
- Posturing is not usually present in arousal parasomnias, while common in nocturnal frontal lobe complex partial seizures.

REM parasomnias arise out of REM sleep and include nightmares and REM behavior disorder. These are more likely in the last half of the night when REM sleep predominates. Nightmares are frightening dreams, the details of which are recalled, an important distinguishing feature from sleep terror. Nightmares often result in awakening from sleep with anxiety. Upon awakening there is full alertness, with no confusion or disorientation, unlike the case with night terrors. While single nightmares are common in normal individuals, recurrent nightmares represent a disorder. REM behavior disorder is motor activity during dreaming. The physiology is thought to be pathological absence of normal sleep paralysis that should be present during REM. The behavior can be quite violent, including punching, kicking, and running movements. REM behavior disorder is more likely in the second half of the night when REM is more prevalent. It is more common after age 50 years, with strong male predominance. It may be seen in some normal patients, particularly as a transient effect of some medications or medication withdrawal. When it is a chronic disorder it is more common in some neurologic disorders, particularly Dementia with Lewy Bodies and Parkinson's disease.

The distinction of REM behavior disorder from frontal lobe seizures is based on the following features:

- The age at onset of REM behavior disorder is usually over 50, later than usual for nocturnal frontal lobe epilepsy
- The REM behavior disorder episodes occur in association with dreams, usually in the second half of the night. Frontal lobe seizures occur at any time during sleep.
- The patients remember their dreams, and the behaviors in sleep are consistent with dream content.
- After arousal from REM behavior disorder, the patient is lucid and oriented.

Sleep talking is a common disorder which affects normal people and is increased in incidence with certain disorders. In older adults, dementia is commonly associated with development of sleep talking. Sleep talking occurs most frequently in Dementia with Lewy Bodies, where it also tends to be loud (Honda et al., 2013). Sleep talking is seldom confused with seizure activity in the absence of other symptoms.

Other parasomnias include a large number of conditions only some of which are potentially confused with seizures. Enuresis is seldom confused with seizure activity, although this, along with finding blood on a pillow, make the thoughtful patients or parents have concern over unobserved nocturnal seizure activity. These findings are not commonly due to seizure in the absence of other manifestations.

Sleep related movement disorders

Restless legs syndrome: RLS is motor restless of the legs which can affect patients day or night, but is worse in the evening or night. The main criterion for diagnosis is an urge to move the legs caused by uncomfortable sensations. The manifestations worsen or start during inactivity and are relieved by movement. In the differential diagnosis of seizure, patients may report twitching of the legs and may emphasize violent jerking which could suggest seizure activity. Sleep myoclonus is often seen in patients with RLS.

Sleep myoclonus: Sleep myoclonus is episodic jerking of lower leg muscles. The jerks can interfere with not only the sleep of the patient but also with sleep of the spouse. Sleep myoclonus is often familial and often seen in patients with RLS, as discussed below. Sleep myoclonus is differentiated from seizure by the occurrence only during sleep, single and irregular nature of the jerks, and absence of ictal or interictal abnormalities on EEG.

Hypnic jerks: Hypnic jerks are the brief jerks which interfere with descent into sleep. They may involve a single limb or the entire body. They are differentiated from seizure activity by the single nature of the jerks, absence of occurrence in awake state or deep sleep. This is a common condition which is considered normal.

Sleep-related rhythmic movement disorder: this is a stereotyped rhythmic movement disorder affecting the head, body or extremities, which can occur with the patient either supine or prone or even on hands and knees. The rocking can cause movement of the bed or actual banging of the head into the headboard, which may be mistaken for seizure activity. The behaviors may result in injury. Young children are most commonly affected. Head banging and other sleep-related rhythmic movement disorder may occur during any stage of sleep. Parents may have difficulty awakening the children, solidifying their concern over seizure activity. The behavior usually lasts less than 15 minutes at a time, but may repeat through the night. Differentiation from seizure activity is mainly by description of the activity. Video-EEG monitoring or polysomnography are rarely necessary for diagnosis.

Migraine and Migraine Equivalent

Migraine can rarely cause episodic symptoms that can be mistaken for seizure activity (Carreño, 2008; Kossoff and Andermann, 2010).

The types of migraine most likely to be confused with seizure activity are:

- Classical migraine with visual aura. Migraine with visual aura can be difficult to distinguish from occipital lobe seizures, which may be followed by a migraine-like headache. Distinguishing features include
- The migraine aura is longer than visual seizures (5 to 60 minutes as compared to less than 30 seconds).
- The visual aura in migraine is most commonly a fortification spectrum or scintillating scotoma, whereas the most occipital lobe seizure aura is colored circles.
- Classical migraine with sensory aura. Both sensory seizure and migraine can have a sensory march, but the sensory march is much shorter in duration in sensory seizures.
- Acute confusional migraine.
- Migraine without headache, or migraine equivalent.
- Basilar migraine.

Episodic vertigo and syncope can be a sign of basilar migraine. One example is a 9-year-old female with episodes that occur about every other day. She becomes irritable and whiny, and this is followed by development of ataxia. She used to become unresponsive, but treatment with levetiracetam has resulted in improvement in this manifestation. Duration is 30–45 minutes.

The first sample, shown in Figure **6-9**, is the baseline normal EEG. This is followed by high-voltage bursts of delta activity (Figure **6-10**). Note the sensitivity of 30 μV/mm.

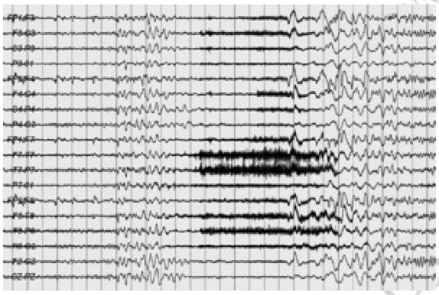

Figure 6-9:

Figure 6-10:

Reflux

Sandifer syndrome is torsional dystonia of the neck and upper arms. This is due to reflux, although the exact pathophysiology is not known. Children with reflux can present with apnea, with or without motor activity that can suggest seizure activity. This, however, is an atypical presentation of reflux; episodic vomiting, poor feeding, and weight loss are more common.

Diagnosis of reflux often depends on cooperative consultation of neurology and gastroenterology. Observation during an episode is key to the diagnosis. These are so common that observations are multiple.

Behavioral Disorders

Behavioral disorders can be mistaken for seizure activity. This activity can include:

- Panic attacks
- Episodic dyscontrol
- Directed violence
- Non-directed violence
- Stereotypic behaviors in cognitively impaired individuals

Panic attacks

A panic attack is defined by the DSM-IV (Craske, 2010) as a “discrete period of intense fear or discomfort, in which four or more of the following symptoms develop abruptly and reach a peak within 10 min:

- Palpitations, pounding heart, or accelerated heart rate
- Sweating
- Trembling or shaking
- Feeling of choking
- Chest pain or discomfort
- Nausea or abdominal distress
- Feeling dizzy, unsteady, lightheaded, or faint
- Derealization (feelings of unreality) or depersonalization (being detached from oneself)
- Fear of losing control or going crazy
- Fear of dying
- Paresthesias (numbness or tingling sensations)
- Chills or hot flushes

Panic disorder is characterized by recurrent unexpected panic attacks at least one of which is followed by persistent concern over additional attacks, worry about the implications and consequences of the attacks, or change in behavior related to the attacks. Some of the above manifestations of panic attacks may be seen with epilepsy, particularly temporal lobe epilepsy. If panic attacks are associated with altered consciousness, then epileptic seizures have to be considered as a more likely alternative.

Episodic dyscontrol or intermittent explosive disorder

This is characterized by recurrent bursts of uncontrollable rage with minimal provocation. The disorder affects children and adults. While this rage can result in violence, it does not have to. Tension and fear as well as other symptoms may precede the outbursts. The subject may report no memory of the events, which can raise the possibility of seizures. Seizure activity is not the cause of rage attacks, although organic brain disease such as traumatic brain injury may predispose to the disorder (Gordon, 1999; McTague et al, 2010).

Directed Violence

Seizure activity has been used as a legal defense for directed violence. Most physicians believe that directed violence does not occur as a result of seizure activity. Plotting, traveling to a crime scene, and attacking an individual are highly unlikely to be due to epileptic seizure activity.

Non-directed Violence

Non-directed violence can be occasionally seen as a component of seizure activity. Motor activity associated with complex partial seizures may appear violent. Biting, hitting, kicking, and scratching are uncommon with epileptic seizures, and when present, are non-directed, affecting only those restraining the patient or in proximity.

Postictal states can be associated with agitation and confusion, resulting in non-directed violence, again especially when trying to fight restraints.

Behavioral abnormalities in association with mental retardation

Children and adults with mental retardation may have repetitive stereotypic movements that can resemble seizure activity. These behaviors may provide sensory stimulation or may help alleviate anxiety. Video-EEG may be necessary to evaluate the nature of the behaviors.

Startle

All of us normally have alerting reactions in response to stimuli that we consider to be novel and important. In startle syndrome, the alerting response is enhanced. This can be present in some patients for unknown reasons, can be inherited, or can be acquired due to CNS disease.

Hyperekplexia was discussed briefly above and is an inherited disorder in which there is exaggerated startle. An unexpected even relatively minor stimulus results in transient stiffness followed by a fall. Hyperekplexia has to be distinguished from epilepsy.

Startle-induced seizures occur in some epilepsies, particularly frontal lobe epilepsy originating in the supplementary motor area. Stimulation induces seizure activity with a startle-like stiffening of the body. In contrast to other startle conditions, there is an electrographic discharge evident with this (Dreissen and Tijssen, 2012).

Peak toxicity of AEDs

Patients taking AEDs may misinterpret symptoms of peak level toxicity as seizures. This is more likely with some AEDs, particularly those acting on the sodium channel. Symptoms may include blurred vision, double vision, dizziness, unsteadiness, and confusion. These manifestations can be distinguished from seizures by

- Longer duration (usually longer than 10 minutes).
- Manifestations of blurred vision or double vision unlikely during seizures.
- The symptoms are temporally related to AED intake.
- The symptoms are more likely with taking the AED on an empty stomach and less likely if the AED is taken with food.
- The symptoms subside with reducing or dividing the dose, or after switching to an extended release preparation.

Drug-induced Encephalopathy

Encephalopathy is the most common cause for neurological consultations in most hospitals. Patients have confusion, memory loss, or other cognitive deficits. Occasional patients may have myoclonic activity and others may have tremor, but it is unlikely that this could be confused with seizure activity.

Tiagabine is an uncommonly used AED, especially for partial seizures. Some patients treated with tiagabine may develop episodes of altered responsiveness and awareness, lasting up to hours. It is not totally clear if this is an encephalopathy or a type of nonconvulsive status epilepticus of the absence variety. Recent reports have shown generalized slow activity in association with the encephalopathy. Reduction in dose of the tiagabine results in disappearance or decreased severity of the episodes (Azar et al., 2013).

Transient ischemic attacks

Transient ischemic attacks (TIAs) are a result of focal transient cerebral ischemia. The main features that help distinguish them from seizures are:

- Chorea is associated with maintained ability to move the limbs, even during the episode of involuntary limb movement.
- TIAs usually manifest with loss of function, while seizures usually manifest with positive manifestations. For example, TIAs involving motor cortex or motor pathways usually manifest with weakness, while seizures involving motor cortex most often manifest with tonic, clonic, or myoclonic activity. Rarely, TIAs with high-grade stenosis or occlusion of the internal carotid artery present with limb shaking (Persoon et al, 2010). One feature that could distinguish "limb shaking TIAs from seizures is precipitation by changing to upright position or by exercise. On the other hand, rarely seizures also may manifest with focal weakness or paralysis (Abou-Khalil et al, 1995).
- Somatosensory TIAs are more likely to manifest with sensory loss, while somatosensory seizures are more likely to cause paresthesias, burning or pain. A sensory Jacksonian march is suggestive of seizure activity, although s sensory march may also be seen with migraine. The sensory march of migraine is much slower
- TIAs usually last longer than seizures. Most seizures last less than 2 minutes, while most TIAs are longer than 5 minutes.

Transient global amnesia

Transient global amnesia is an episode of memory loss without impairment of other cognitive function. Affected subjects do not forget their identity and are still able to engage in complex activities during the attacks. Transient global amnesia usually lasts hours, but recovers within 24 hours of onset. Older individuals are more likely to be affected. Single isolated attacks occur in most instances, but attacks may repeat in a minority of individuals. The pathophysiology of transient global amnesia is not totally clear and may be different in different individuals (Hunter, 2011).

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Atlas of EEG, Seizure Semiology, and Management

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Medical

Initiation of Therapy

If and When to Initiate Therapy

Anti-epileptic drugs (AEDs) are prescribed for most but not all patients with seizures. Some of the clinical scenarios that may not require medical treatment include:

- Single unprovoked seizure;
- Provoked seizure(s);
- Benign epilepsy of childhood with centrotemporal spikes (BECTS) with infrequent seizures;
- Juvenile myoclonic epilepsy (JME) with myoclonic seizures only.

A single unprovoked seizure has a relatively low risk of recurrence with a normal neurologic exam, normal MRI, and normal EEG (see Figure **7-1**). Risk of recurrence after a single unprovoked seizure is about 40–50% overall at 2 years. However, patients with normal neurological examination, normal imaging, and normal EEG have a significantly lower rate of approximately 25%. Observation without treatment may be warranted in such cases, provided a seizure recurrence does not involve undue risk to the patient or to the patient's career.

Figure 7-1:

Single provoked seizure due to metabolic derangement/toxic exposure, acute head injury, or other limited central nervous system (CNS) insult does not necessarily demand AED therapy. If the seizures recur, then initiation of therapy appropriate to the seizure type is warranted. The duration of treatment is dependent on how quickly the provoking factor can be reversed. It can be for only a few days. If the provoking factor cannot be immediately reversed, such as the case with an inflammatory process, the duration of treatment may be as long as several months. Febrile seizures usually do not need long-term seizure medicine. The risk of recurrence is 30–40% but multiple recurrences are infrequent. Children with frequent recurrences can be treated with oral or rectal diazepam at the time of illness.

Benign epilepsy with centrotemporal spikes (BECTS) may manifest with seizures that are infrequent, occur mainly at night, and spontaneously remit before driving is an issue, so treatment is not always necessary.

JME in selected patients might be relatively mild, manifesting with only myoclonic seizures. It may be managed by self-help guidelines (e.g., avoid sleep deprivation, alcohol binges, and certain medications). In these patients AEDs may not be needed. However, unlike with BECTS, this is a relatively small proportion of the JME patient population.

Recurrent Unprovoked Seizures

Recurrent unprovoked seizures usually deserve AED therapy. With more than one unprovoked seizure, the risk of recurrence is much more likely than not. More than two-thirds of individuals will have a seizure recurrence. Treatment is usually initiated with a single AED. It is preferable to start at a low dose and titrate slowly, unless there is a reason for urgency. For many AEDs, the starting dose can be even lower than recommended in the prescribing information. The initial target dose is usually the smallest dose found effective in clinical trials. However, for some AEDs an even smaller dose has been found effective after marketing. For example, lamotrigine 125–200 mg per day was sufficient for seizure control in most patients with new onset epilepsy, while the smallest dose found effective in add-on trials was 300 mg per day (Kwan and Brodie, 2001). If the initial target dose is not sufficient to control seizures, the dose can then be increased gradually until seizure control is achieved or adverse effects appear. There is an important exception to this guideline in patients with infrequent seizures. For these patients it is best for the initial target dose to be a “middle of the road” dose. Below are the recommended initial treatment options, depending on seizure classification.

Partial

Partial-onset seizures have traditionally been treated with carbamazepine or phenytoin. However, these older agents have been largely replaced by some of the newer AEDs, which have pharmacokinetic and tolerability advantages (see Table 7-1). Among the new AEDs, FDA approval has been given for oxcarbazepine and topiramate as first-line treatments. However, good clinical evidence supports the effectiveness of lamotrigine, levetiracetam, and gabapentin. Lamotrigine seems to be particularly attractive due to favorable tolerability (particularly less effect on cognition and alertness) but the slow titration is a limiting factor when rapid onset of action is needed. However, even in this situation, it is worthy of consideration for later transition. The large Standard and New Antiepileptic Drug (SANAD) trial comparing lamotrigine, carbamazepine, gabapentin, oxcarbazepine, and topiramate in partial epilepsy favored lamotrigine for the primary outcome measure, balancing efficacy and tolerability (Marson et al., 2007). Topiramate also requires a slow titration, and it has important cognitive potential adverse effects. As a result, it is usually not a first-choice treatment, unless there is comorbidity such as migraine and obesity. When rapid onset of action is needed, the new AEDs to be considered as first-line treatment are levetiracetam and oxcarbazepine.

Table 7-1 Anti-epileptic Drugs	
Drug	***Clinical use***
Carbamazepine (Tegretol)	Partial-onset, generalized tonic-clonic (may aggrevate myoclonic and absence seizures),
Clobazam (Onfi)	Lennox-Gastaut syndrome.
Clonazepam (Klonopin)	Lennox-Gastaut (absence type, atonic, and myoclonic seizures) as adjunctive or monotherapy.
Ethosuximide (Zarontin)	Absence
Ezogabine (Potiga)	Partial-onset seizures in adults as adjunctive therapy.
Felbamate (Felbatol)	Partial-onset seizures in adults. Only for highly refractory cases. Adjunctive therapy for generalized seizures in children with Lennox-Gastaut
Gabapentin (Neurontin)	Adjunctive therapy for partial-onset seizures.
Lacosamide (Vimpat)	Adjunctive therapy for partial-onset seizures.
Lamotrigine (Lamictal)	Adjunctive therapy for partial-onset, primary generalized tonic-clonic, generalized seizures of Lennox-Gastaut. Monotherapy for partial-onset seizures.
Levetiracetam (Keppra)	Adjunctive therapy for partial-onset seizures, myoclonic seizures of JME, primary generalized tonic-clonic seizures in patients with idiopathic generalized epilepsy. Initial monotherapy for partial-onset and primary generalized tonic-clonic seizures.
Methsuximide (Celontin)	Absence seizures refractory to other AEDs. May be used as adjunctive therapy for partial-onset seizures resistant to other AEDs.
Oxcarbazepine (Trileptal)	Partial seizures as monotherapy or adjunctive therapy in adults and children.
Phenobarbital (Luminal)	Broad range of seizures except absence.
Phenytoin (Dilantin)	Tonic-clonic, partial-onset, post-operative seizures (May aggravate myoclonic and absence seizures).
Primidone (Mysoline)	Broad range of seizures including primary generalized tonic-clonic, partial-onset seizures. Used alone or in combination. May also be effective for myoclonic seizures.
Pregabalin (Lyrica)	Partial-onset seizures in adults as adjunctive therapy.
Rufinamide (Banzel)	Lennox-Gastaut
Tiagabine (Gabitril)	Partial-onset seizures as adjunctive therapy
Topiramate (Topamax)	Adjunctive therapy or initial monotherapy for partial-onset or primary generalized tonic clonic seizures. Adjunctive therapy for seizures associated with Lennox-Gastaut syndrome
Valproate (Depakote, Depakene, Depacon iv)	Broad range of seizures including partial-onset seizures as well as generalized-onset seizures (including absence).
Vigabatrin (Sabril)	Adjunctive therapy for adults with refractory partial-onset seizures, who have tried several alternatives and in whom the potential benefits outweigh the potential loss of peripheral vision.
Zonisamide (Zonegran)	Partial-onset and generalized-onset seizures in adults as adjunctive therapy. Monotherapy fo partial-onset seizures supported by recent study.

Generalized

Absence seizures: Ethosuximide is the drug of choice for initiating therapy in most patients with generalized absence seizures. If the patient has coexistent generalized tonic-clonic or myoclonic seizures, then valproate is a better choice. Lamotrigine was found to be less effective than ethosuximide and valproate for absence seizures in a large comparative trial (Glauser et al., 2010). Nevertheless, it is an important option in a woman of childbearing potential (due to valproate teratogenicity) or in a man with comorbidities that prohibit the use of valproate (such as obesity).

Idiopathic generalized epilepsy with generalized tonic-clonic seizures: Valproate appears to be the most effective agent and is the drug of choice for men, but because of the risk of birth defects and other developmental abnormalities, lamotrigine and levetiracetam are preferable first-choice options for women with childbearing potential.

Generalized myoclonic seizures: Valproate is likely the most effective agent as monotherapy. Levetiracetam is approved for adjunctive therapy but may also be effective in monotherapy. Other agents have weaker evidence for efficacy and no FDA indication. Lamotrigine may be effective in some individuals, but may also exacerbate myoclonic seizures in others. Topiramate, zonisamide and benzodiazepines may also be effective in some individuals (see Table 7-2).

Table 7-2 Spectrum of Efficacy					
Anti-epileptic drug	***Seizure type indication***				
	Partial	**Generalized tonic-clonic**	**Generalized Absence**	**Generalized Myoclonic**	**Tonic/atonic in the setting of Lennox- Gastaut syndrome**
Phenobarbital		FDA	–	–	–
Primidone		FDA	–	+	–
Phenytoin		FDA	–	–	–
Methsuximide	+	–	FDA	–	–
Ethosuximide	–	–	FDA	–	–
Clonazepam	+	+	FDA-A	FDA-A	FDA-A
Carbamazepine		FDA	–	–	–
Valproate	FDA-M	++	FDA-M	++	++
Vigabatrin*	FDA-A	–	–	–	–
Felbamate	FDA- A/MC	+	–	–	FDA- A
Gabapentin	FDA- A	–	–	–	–
Lamotrigine	FDA- MC/A ++ MI	FDA- A	+	+/–	FDA- A
Topiramate	FDA- MI/A	FDA- A	+/–	+	FDA- A
Tiagabine	FDA- A	–	–	–	–
Levetiracetam	FDA- A++ MI	FDA- A	+	FDA-A	+/–
Oxcarbazepine	FDA- MI/A	–	–	–	–
Zonisamide	FDA- A++ MI	+	+	+	+
Pregabalin	FDA- A	–	–	–	–
Lacosamide	FDA- A	–	–	–	–
Rufinamide	+	–	–	–	FDA– A
Clobazam	+	+	+	+	FDA– A
Ezogabine	FDA- A	–	–	–	–
Perampanel	FDA- A	–	–	–	–

FDA = FDA-approved indication without specification as to adjunctive versus monotherapy indication.

FDA-A = FDA-approved indication for adjunctive therapy

FDA-MI = FDA-approved indication for initial monotherapy

FDA-MC = FDA-approved indication for monotherapy conversion

FDA-M = FDA-approved indication for monotherapy without specification as to initial monotherapy or conversion to monotherapy

++ = class 1–3 evidence of efficacy

++ MI = class 1–3 evidence of efficacy as initial monotherapy

+ class 4 evidence of efficacy

+/– inconsistent evidence of efficacy (some reports suggests lack of efficacy or exacerbation)

* Also approved for infantile spasms

Considerations in Therapy

Age

Age plays a complex role in drug selection, mainly in relation to medication tolerability and safety. The best-known age-related association is hepatic failure with valproate, most common in children under 2 years old. Also more common in children are rash from lamotrigine, and behavioral effects of some medications such as phenobarbital and levetiracetam. On the other hand, children under 13 do not seem at risk of aplastic anemia from felbamate.

Older age predisposes to hyponatremia from carbamazepine and particularly oxcarbazepine. Seniors also are more likely to experience the common adverse effects of somnolence and ataxia. Also, seniors are more likely to be on multiple drugs, hence a predisposition to drug-drug interactions. Lastly, seniors are more likely to have reduced hepatic and renal clearance, requiring consideration in dosing. In general, lamotrigine and gabapentin are better tolerated in the elderly than carbamazepine (Rowan et al., 2005). However, administering carbamazepine in an extended release preparation improves its tolerability.

Pregnancy and Childbearing Potential

Many patients taking anti-epileptic drugs are women of childbearing age. While many of these are taking the medications for epileptic indications, a considerable number are taking them for other uses, including migraine prophylaxis and psychiatric indications. When a woman considers pregnancy or becomes pregnant, cessation of medications is considered, but this is potentially unsafe when AEDs are given for epilepsy; there are considerable risks to the mother as well as potential deleterious effects of uncontrolled seizures to the fetus. In addition, by the time the patient is found to be pregnant, much of the teratogenicity on major organs has already taken effect, so cessation of the AED at that point does not protect against major organ birth defects.

To lower the incidence of birth defects in women with epilepsy and to optimize pregnancy outcome, it is essential to have a discussion of changes in AED therapy prior to planned pregnancy. While there is debate about which AEDs are safest, there are AEDs to be avoided. The FDA has a classification that provides a general guideline regarding safety in pregnancy (see Table 7-3).

Table 7-3 AED use in renal impairment		
	Dose change with renal impairment	**Replacement after dialysis**
Phenobarbital	Reduce slightly based on level	Supplement based on level
Primidone	Reduce slightly based on level	Supplement based on level
Phenytoin *	No change	No change
Methsuximide	No change	**
Ethosuximide	No change	Supplement one dose
Clonazepam	No change	No change
Carbamazepine	No change	No change
Valproate *	No change	No change
Felbamate	Reduce dose by 50%	**
Gabapentin	Reduce dose by 50–90%	Supplement one dose
Lamotrigine	Reduce by 0–20%	Supplement 20% of dose
Topiramate	Reduce by 50%	Supplement ?% of dose
Tiagabine	No change	No change
Levetiracetam	Reduce dose by 50–70%	Supplement one dose
Oxcarbazepine	Reduce dose by 0–50%	No change ?
Zonisamide	Reduce by up to 35%	Supplement ?% of dose
Pregabalin	Reduce dose by 50–85%	Supplement one dose
Lacosamide	Reduce dose by 0–30%	Supplement 50% of dose
Rufinamide	Not affected	Supplement 30% of dose
Vigabatrin	Reduce dose by 25–75%	Supplement half dose
Ezogabine	Reduce dose by 0–50%	**
Perampanel	Not recommended with several renal impairment	**
Clobazam	No change	**

* Low protein state associated with renal impairment requires monitoring of protein free serum level.

** No recommendations on the basis of available data.

FDA pregnancy classification:

- *Category A*: Safe in humans—studies have failed to demonstrate a risk to the fetus in the first trimester of pregnancy.
- *Category B*: Safe in animals—unknown in humans or adverse effect in animals, but human studies suggest it is safe.
- *Category C*: Adverse effect in animals, not enough data in humans; potential benefits may warrant use in pregnancy.
- *Category D*: Adverse effect on the human fetus; potential benefits may warrant use in pregnancy.
- *Category X*: Adverse effect on human fetus; risks clearly outweigh potential benefits in pregnancy.
- *Category N*: FDA has not classified this drug.

Most but not all AEDs are assigned a pregnancy category. Some of the older drugs do not have categories assigned by the FDA because of differences in the approval process. Some have been stated to have a pregnancy category by investigators on the basis of recent findings, but these categories will typically not be found on published prescribing information. Note that all AEDs with a pregnancy category are in either category C or D.

No drug is without risk during pregnancy, and no drug consistently provides perfect seizure control. But in general the authors prefer to use lamotrigine, levetiracetam, or oxcarbazepine during pregnancy. Valproate is associated with a dose-dependent increased risk of birth defects. It was once believed that valproate was problematic mainly during the first trimester and safe for use later in pregnancy, once major organs have formed, but more recent data demonstrate adverse cognitive and behavioral adverse effects, and support avoiding valproate at all stages of pregnancy if possible (Meador et al., 2013).

The North American AED Pregnancy Registry organized through Massachusetts General Hospital (MGH) is a massive database of patients exposed to AEDs for seizures as

well as non-epileptic indications. Patients continue to be enrolled, so physicians of all specialties using these drugs on women of childbearing potential should advise patients to enroll in the registry if they become pregnant. Recent data just released from the registry compares AEDs for risk of birth defects (Hernández-Díaz et al., 2012). Note that many AEDs have very limited experience in monotherapy, so that their safety in pregnancy cannot yet be concluded. For example, there were no malformations in the zonisamide monotherapy group, but there were only 90 pregnancies on zonisamide monotherapy at the time of reporting.

Before Pregnancy

Managing AEDs in a woman with childbearing potential should be proactive when at all possible, and there should be counseling prior to pregnancy. There should be discussion as to which medications are the most appropriate for the seizure type, which AEDs place the fetus at higher risk for defects, and what the risk of seizures is for the fetus. Because of the imperfect data and complexity of the decision-making process, each case must be individualized, and the ultimate decision is made by the patient and physician together. There should certainly be an effort to reduce the medication load in women taking multiple AEDs. If the patient has pure absence or pure subjective simple partial seizures, withdrawal of seizure medications can be considered. If a patient is on valproate, then a change to an alternative, such as lamotrigine, should be considered.

Some examples follow:

- A 19-year-old woman with absence epilepsy has been seizure-free on ethosuximide for two years. She has never had another type of seizure besides generalized absence. After discussion with the physician, she decides to discontinue ethosuximide before pregnancy. She is not expected to develop any seizures that would be dangerous to the child. She decided to remain off the drug even if absence seizures recur.
- A 25-year-old woman with generalized tonic-clonic seizures is well controlled on valproate, given for both seizures and migraines. Considering the high risk of birth defects and cognitive as well as developmental risks of valproate, it was recommended that she should switch to another AED. After discussion with the physician, she transitions off valproate to lamotrigine.

Folate and multivitamin supplementation reduce the incidence of birth defects associated with AEDs. Folate use is also associated with higher IQ in children exposed to AEDs in utero. We recommend supplementation at prenatal doses for women with any reasonable risk of pregnancy, particularly those who are actively trying to get pregnant.

During Pregnancy

Management is much more complex when the patient presents after she is already pregnant. All of the same factors discussed above will be considered, but there is a sense of concern that a substantial portion of the risk of major malformations has already been experienced, so while medications may need to be changed, in some respects damage has already been done. In addition, a trial off AEDs during pregnancy is riskier than before pregnancy. Simplification of AED polytherapy would still be appropriate. In addition, patients who become pregnant on valproate should be changed to an alternative agent if possible. Although exposure to valproate in the beginning of pregnancy is associated with risk of major malformation, later exposure also can result in lower IQ and other developmental abnormalities (Meador et al., 2012; Meador et al., 2013).

All patients who are pregnant should be on multivitamin supplementation, including prenatal doses of folate.

AED blood levels have to be monitored more closely during pregnancy than before, because of changes in metabolism and volume of distribution. In particular, lamotrigine level is lowered by estrogen in the second trimester, with a higher risk of breakthrough seizures, so the dose usually has to be increased. Following delivery, the dose has to be decreased. It is recommended that the dose is brought back to what it was before pregnancy in two steps: half the reduction the day of delivery and the other half after one week.

Comorbid Conditions

Numerous comorbid conditions alter potential AED selection and dose management. Some comorbid conditions are effectively treated with certain AEDs, which makes these AEDs preferable. AEDs with FDA-approved non-epileptic indications include:

- Topiramate for migraine prophylaxis;
- Valproate for migraine prophylaxis and acute treatment and maintenance for mania/bipolar disorder;
- Lamotrigine for maintenance for bipolar disorder;
- Clonazepam for panic attacks;
- Carbamazepine for trigeminal neuralgia;
- Gabapentin for postherpetic neuralgia and restless leg syndrome (for gabapentin enacarbil);
- Pregabalin for diabetic peripheral neuropathy, postherpetic neuralgia, and fibromyalgia.

In addition, several AEDs are used without official FDA indication in the treatment of headaches (particularly gabapentin), insomnia (gabapentin and pregabalin), restless leg syndrome (gabapentin and pregabalin), and essential tremor (primidone and topiramate). On the other hand, some comorbid conditions can be exacerbated by certain AEDs, which makes them less desirable. For example, patients with obesity should avoid valproate, carbamazepine, and pregabalin, which can cause weight gain. Topiramate and zonisamide, which can cause weight loss, could then be favored. Topiramate and zonisamide are relatively contraindicated in individuals with kidney stones. Patients with psychosis should avoid topiramate, zonisamide, and levetiracetam. While we cannot be complete in this discussion, below are some general guidelines.

Migraine: the coexistence of epilepsy and migraine is common. Topiramate and valproate both have FDA indications for migraine and could be considered if the frequency of migraine attacks justifies prophylactic therapy.

Bipolar disorder: valproate and lamotrigine have FDA indications for bipolar disorder. The former would be favored for predominant mania and the latter for predominant depression. Carbamazepine, oxcarbazepine, and topiramate have also been used off-label for bipolar disorder.

Hepatic insufficiency: Valproate and other agents with principal hepatic metabolism should be avoided if possible. If used, dose adjustment is needed.

Renal insufficiency: Renal insufficiency reduces the clearance of many drugs with renal elimination, so that lower doses have to be used. In addition, patients on hemodialysis may need to be redosed after dialysis.

Chemotherapy and immune modulators: Some chemotherapeutic agents and anti-rejection medications have their metabolism altered by enzyme-inducing AEDs. For some of these medications, this reduces the efficacy of treatment or makes the cost of therapy substantially higher.

Epileptic Syndrome and Genetics

At present, the seizure type is the main predictor of response, and epileptic syndrome plays limited role. There are only rare exceptions. For example, autosomal dominant nocturnal frontal lobe epilepsy responds particularly well to carbamazepine and oxcarbazepine. However, there are also instances where the epileptic syndrome diagnosis makes a particular AED undesirable. For example, lamotrigine and other sodium channel-blocking AEDs are known to aggravate severe myoclonic epilepsy of infancy (Dravet syndrome). Phenytoin is contraindicated in progressive myoclonic epilepsies because it can worsen progressive ataxia and cause dementia. It is expected that genetics and syndrome diagnosis will have a greater role in medication selection in the future, as the pathophysiology of epilepsy is better understood.

Adverse Effects

Adverse effects can be easily accessed by online references. These include dailymed.nlm.nih.gov as well as product-specific websites. Note that there are some common reported adverse effects, including dizziness, gait difficulty, nausea, headache, rash, and somnolence. Comparing the frequency of these symptoms in patients treated with active drug compared with patients treated with placebo can give us a good indication of how often these can be attributed to the drug. In addition, there are often numerous adverse effects listed for which there is no clear cause-and-effect relationship with the AED.

Dosing for First-line Therapy

The dosing for first-line therapy is described for most common used AEDs in Figures 7-12 to 7-19. It is essential to be familiar with the pharmacokinetics of AEDs for best use, and particularly for dosing schedule (see Table 7-4).

Table 7-4 Pharmacokinetic Properties of AEDs Appropriate as Initial Monotherapy

AED	Oral absorption/ bioavailabilityHigh: ≥90 %Intermediate: ≥70%–<90%Low: <70%	Half-life (hours) Short: ≤10Intermediate: >10–30<Long: ≥30	Extended release preparation	Intravenous preparation	Metabolism+ <50%++ >50% – <90%+++ >90%
Phenobarbital	High	Long	–	Yes	++ Liver
Phenytoin	High	Intermediate	Yes	Yes	+++Liver
Ethosuximide	High	Long	–	–	++Liver
Carbamazepine	Intermediate	Intermediate	Yes	–**	+++Liver
Valproate	High	Intermediate	Yes	Yes	+++Liver
Gabapentin	Low	Short	–*	–	None
Lamotrigine	High	Intermediate	Yes	–	+++Liver
Topiramate	Intermediate	Intermediate	–**	–	+Liver
Levetiracetam	High	Short	Yes	Yes	+Blood
Oxcarbazepine	High	Intermediate¶	–**	–	+++Liver
Zonisamide	High	Long	–	–	++Liver

* Not approved for epilepsy

** In development

¶ Combination of parent drug and active metabolite monohydroxyderivative

Drug-Level Monitoring

AED levels are measureable for most AEDs. AED serum levels should only assist in clinical decision making, and should not be the primary basis for dosing decisions. A "therapeutic range" has been suggested for some AEDs. This is best established for the old AEDs phenytoin, carbamazepine, and valproate, and is also helpful for lamotrigine and oxcarbazepine. The range is only a useful guide, and a value outside the range should not be the only reason to change the dose. Routine AED levels are not necessary.

AED levels are most helpful in the following situations:

- As a reference value once a clinically effective dose has been reached.
- Verifying that the AED level is within the effective range for a patient with infrequent seizures, for whom ascertainment of effective seizure control may take a very long time. In this case, the neurologist would aim for a level in the middle of the range.
- Monitoring phenytoin level during titration in a patient with difficult to control seizures. Because of non-linear kinetics, the level may increase excessively with a small increment in the dose. The level may need to be checked intermittently during the process of titration. At a serum level near 20 mcg/ml, additional titration may result in toxicity.
- Verifying stability of AED level for phenytoin, which has non-linear kinetics. The phenytoin level can fluctuate widely with a small change in dose or small change in absorption.
- After a breakthrough seizure occurs, to determine if the breakthrough seizure was related to a drop in the serum level.
- To help explain lack of AED efficacy at what appears to be a high dose. A low level despite a high dose may indicate that the patient is a high metabolizer or is not compliant. A low level may encourage repeating the measurements to verify stability. Large variability may suggest inconsistent compliance. If the patient is compliant, a low level indicates room for further increases in dosing if needed for seizure control, even at the maximal dose recommended in the prescribing information. Undetectable levels despite a high dose suggest non-compliance.
- To help explain appearance of adverse effects at a relatively low dose. A high level may suggest that the patient is a slow metabolizer and a lower dose may be indicated.
- To watch for pharmacokinetic interactions after introduction of another medication that may affect the baseline AED.
- To monitor AED level during pregnancy, which is known to reduce some AED levels.
- To monitor stability of AED level when switching to a different formulation or a different brand.

For highly protein-bound AEDs such as phenytoin and valproate, the protein-free portion is responsible for efficacy and toxicity. When these AEDs are used in monotherapy in an otherwise healthy individual, the total serum level is a good predictor of the protein-free level. However, measuring protein-free levels will be important in states that may change the proportion of binding, such that the total level is no longer a predictor of the protein-free level. These clinical situations include low protein states such as renal failure, hepatic failure, malnutrition, and old age, pregnancy, or concomitant use of phenytoin and valproate, with resultant competition for protein binding. Phenytoin and valproate are both approximately 90% protein-bound. Protein-binding of valproate can be saturated at high doses, at which point the free level may be much higher than predicted by the total serum level.

AED levels should generally assist therapy rather than direct it. With some exceptions, it is generally not appropriate to drive the AED dose to achieve a level in the "therapeutic range," because the definition of the therapeutic range is arbitrary to a certain extent. If there is a good clinical response, then measurement of the level can show what an effective level is for that patient. One exception to the above rule is the patient with very infrequent seizures. In such a case, it may take a very long time to determine if the treatment has been successful. It is then recommended to titrate to a middle-range dose or a middle-range level.

If the seizures are not controlled on what would normally be a reasonable target dose, then measurement of the level can determine whether there is room to increase the dose further. Toxicity is usually determined by clinical symptoms rather than levels. However, if the drug level is significantly higher than the published upper limit of "therapeutic range," then further increase in dose is likely not warranted. On the other hand, if good seizure control is achieved by a level that is somewhat higher than the "therapeutic range" yet there are no symptoms or signs of toxicity, then the dose should usually not be reduced despite the high level.

If a patient has loss of seizure control, one of the possible reasons is reduction in blood level, either due to missing doses or change in metabolism. Missing doses is a major cause of reduced drug level. Altered metabolism can be from exposure to a new drug (e.g., antibiotic) or alcohol.

Some drugs have non-linear kinetics, so small changes in dose can produce large changes in levels. Phenytoin is currently the only AED with non-linear kinetics. At low levels, small dose changes produce small changes in level, whereas at higher levels (e.g., mid-to-high therapeutic) small dose changes can produce large changes in level. As phenytoin is being pushed to maximal therapeutic levels, careful monitoring of the level is warranted (see Table 7-5).

Table 7-5 Anti-epileptic Drug Levels

AED	Lower end of range (mcg/ml)Breakthrough seizures more likely below this value	Higher end of range (mcg/ml)Toxicity more likely above this value
Phenytoin	Total level: 10 Free level: 1	Total level: 20 Free level: 2
Carbamazepine	4	12
Valproate	Total level: 50 Free level: 5	Total level: 100 Free level: 10
Lamotrigine	2	20
Oxcarbazepine (level measures MHD metabolite)	10	35

Most useful AED serum level range; note that these value are merely statistical, suggesting increased risk of seizures below the lower end of range and increased risk of toxicity above the upper end of the range.

Second-line Therapy

If an AED is not tolerated, it should be replaced with another. However, if an AED trial fails due to lack of efficacy, there are more options. Before an AED trial has been declared a failure, it is important to review a number of questions:

- Has the medication been titrated to the maximum tolerated dose?
- Has the patient been compliant with the medication?
- Are the breakthrough seizures provoked by factors that can be corrected, such as sleep deprivation, alcohol or drug abuse, or concomitant use of a medication known to reduce the seizure threshold?

If it is determined that the AED has truly failed due to lack of efficacy, the physician can choose to replace it with another AED in monotherapy or add another AED. Studies do not show a difference in efficacy and side effects between these two options, although there is a slight trend favoring adjunctive therapy with another medication (Beghi et al., 2003; Kwan and Brodie, 2000b). From a commonsense perspective, replacement monotherapy is the best choice if the first AED was completely ineffective. However, if the first AED was partially effective, adding a second AED may be a better consideration. Replacing the first AED usually requires first adding the new AED before withdrawing the old one. It is acceptable and sometimes advantageous to reduce the dose of the first AED as the new AED is titrated. An overnight switch is possible for some AEDs, provided the doses are not high. An overnight switch has been well tested for carbamazepine to oxcarbazepine conversion using a 2 to 3 dose ratio, provided the dose of carbamazepine is 800 mg or less. Based on some similarity in properties and mechanism (but without supportive published evidence), one of the authors also switches gabapentin to pregabalin using a 6 to 1 ratio (if the gabapentin dose is 1800 mg or less), and topiramate to zonisamide (using a 1 to 1 ratio for a dose of 200 mg or less).

All AEDs are FDA approved for adjunctive therapy. Table 7-6 outlines the pharmacokinetic properties of AEDs that are not candidates for initial therapy.

Table 7-6 Pharmacokinetic Properties of AEDs Not Appropriate as Initial Monotherapy					
AED	**Oral absorption/ bioavailability High: ≥90 % Intermediate: ≥70%–<90% Low: <70%**	**Half-life (hours) Short: ≤10 Intermediate: >10–30< Long: ≥30**	**Extended release preparation**	**Intravenous preparation (USA)**	**Metabolism + <50% ++ >50%– <90% >90%**
Primidone	High	Intermediate*	–	–	++Liver
Clonazepam	High	Long	–	–	++Liver
Methsuximide**	High	Long	–	–	+Liver
Felbamate	High	Intermediate	–	–	++Liver
Tiagabine	High	Short	–	–	+++Liver
Pregabalin	High	Short	–	–	None
Lacosamide	High	Intermediate	–	Yes	+Liver
Rufinamide	Intermediate	Short	–	–	+++Liver
Vigabatrin	High	Short¶	–	–	None
Ezogabine	Low	Short	–	–	++Liver
Clobazam	High	Long	–	–	+++Liver
Perampanel	High	Long	–	–	+++Liver

* Long for the metabolite phenobarbital

** applies to active metabolite desmethylmethsuximide

¶ The duration of effect is longer than expected from T1/2 because the drug works through irreversible inhibition of GABA transaminase enzyme.

Adding a new AED to an old one should consider interactions between the two AEDs. The interaction can be pharmacokinetic (for example, a change in the serum level of the old drug as the new one is added) or pharmacodynamic (no change in the level of the old AED, but increased toxicity because of additive adverse experiences, for example). Some pharmacodynamic interactions are favorable, with evidence of synergy. Such beneficial additive effects are best demonstrated for the combination of lamotrigine and valproate. Another combination that seems to be particularly helpful is that of lamotrigine and levetiracetam, but it has less support in the literature. In general, there is a suggestion that an AED combination with different mechanisms may be more efficacious than a combination of two AEDs with the same mechanism (see Table 7-7). For the recommended AEDs as second- and third-line therapy, please refer to Table 7-8.

Table 7-7 Key Known AED Mechanisms of Action

AED	Sodium channel blocking	Potassium channel opening	Enhancing GABA	Glutamate receptor antagonism	Blocking high voltage activated calcium channels	Blocking T-calcium channels	Binding Alpha-2-delta subunit of voltage-activated calcium channels	Binding SV2A	Comment
Phenobarbital			X	X	X				
Primidone			X	X					
Phenytoin	X								
Methsuximide	X?					X			
Ethosuximide						X			
Clonazepam and clobazam			X						
Carbamazepine	X								
Valproate	X		X			X			
Felbamate	X		X	X	X				NMDA receptor antagonism
Gabapentin							X		
Lamotrigine	X				X				
Topiramate	X		X	X					Kainate and AMPAReceptor antagonism
Tiagabine			X						Inhibition of GABA reuptake
Levetiracetam								X	
Oxcarbazepine	X								
Zonisamide	X			X		X			
Pregabalin							X		
Lacosamide	X								Selective enhancing of slow inactivation of voltage-gated sodium channels
Rufinamide	X								
Vigabatrin			X						Irreversible inhibition of GABA transaminase
Ezogabine		X							
Perampanel				X					Selective noncompetitive antagonism of the AMPA receptor

Table 7-8 AEDs for First Through Later Lines of Therapy

First-line, second-line, third-line, and late consideration AEDs (listed in general order of consideration). First-line agents are always considerations for second- and third-line therapy. The table does not follow FDA indications.

	Partial-onset	**Primary generalized tonic-clonic**	**Generalized absence**	**Generalized myoclonic**	**Generalized tonic-atonic in LGS**
First-line	Lamotrigine Levetiracetam Oxcarbazepine Topiramate Zonisamide Carbamazepine Phenytoin Valproate Phenobarbital Gabapentin	Valproate Lamotrigine Levetiracetam Topiramate	Ethosuximide Valproate Lamotrigine	Valproate Levetiracetam	Valproate
Second- and third-line	All above Pregabalin Lacosamide Ezogabine Tiagabine Clobazam Perampanel Methsuximide Clonazepam	All above Zonisamide Clonazepam Lacosamide Rufinamide Clonazepam Clobazam	All above Levetiracetam Zonisamide Clonazepam Clobazam Methsuximide	All above Zonisamide Topiramate Lamotrigine* Clonazepam Clobazam	Rufinamide Lamotrigine Topiramate Clobazam Clonazepam
Late consideration	Vigabatrin Felbamate Primidone	Phenytoin** Carbamazepine** Phenobarbital Primidone Methsuximide Felbamate	Topiramate*** Felbamate	Primidone Felbamate	Zonisamide Levetiracetam Lacosamide Felbamate

* May worsen myoclonic seizures in some patients

** May activate myoclonic and absence seizures in some patients

*** Ineffective in one controlled trial

Drug Interactions

Pharmacokinetic interaction implies that the addition of an AED to another results in a change in serum level. Factors that make a drug more likely to interact are enzyme induction or inhibition, liver metabolism, and high protein binding. Table 7-9 shows the potential of AEDs to interact based on these properties.

Table 7-9 Pharmacokinetic Interactions

Anti-epileptic drug	Hepatic enzyme induction	Autoinduction	Hepatic enzyme inhibition	Affected by enzyme inducers	Affected by enzyme inhibitors	Protein binding
	+ minimal (usually selective) ++ intermediate +++ pronounced – absent	+ affected – not affected	High ≥85% Low<85%			
Phenobarbital	+++	–	–	+	+	Low
Primidone	+++	–	–	+	+	Low
Phenytoin	+++	–	–	+	+	High
Methsuximide	+	–	–	+	–	Low
Ethosuximide	–	–	–	+	–	Low
Clonazepam	–	–	–	–	–	High
Carbamazepine	+++	+++	–	+	+	Low
Valproate	–	–	+++	+	+	High
Felbamate	+	–	++	+	+	Low
Gabapentin	–	–	–	–	–	None
Lamotrigine	+	+	–	+	+	None
Topiramate	+ ¶	–	+ ¶	+	–	Low
Tiagabine	–	–	–	+	–	High
Levetiracetam	–	–	–	+/–	–	Low
Oxcarbazepine	++ **	–	+**	+	+	Low
Zonisamide	–	–	–	+	+	Low
Pregabalin	–	–	–	–	–	None
Lacosamide	–	–	–	+	–	Low
Rufinamvide	+	–	+	+	+	Low
Vigabatrin	+	–	–	–	–	None
Clobazam	+	–	+	–	+	Intermediate
Ezogabine	–	–	–	+	–	Low
Perampanel	+	–	+	+	+	High

¶ applies to dose ≥ 200 mg

** applies to dose ≥ 900 mg

The most common pharmacokinetic interactions are a result of enzyme induction resulting in increased clearance and lower serum level, or enzyme inhibition resulting in decreased clearance with resulting accumulation and increased serum level.

Some AEDs such as carbamazepine, phenytoin, and phenobarbital produce profound and widespread enzyme induction and result in reduced levels of other AEDs that are metabolized by the liver. The greater the liver metabolism of an AED, the more it is affected by enzyme inducers. This is why it can be very difficult to achieve a therapeutic level of valproate in the presence of carbamazepine or phenytoin. The increased metabolism can also increase the production of toxic metabolites that mediate some types of valproate toxicity. Other AEDs have more modest and more selective enzyme induction. For example, oxcarbazepine enzyme induction is more specific for hepatic enzymes responsible for the metabolism of some calcium antagonists, oral contraceptives, and cyclosporin. However, oxcarbazepine does not affect valproate or warfarin levels, which are markedly affected by carbamazepine.

Valproate is a hepatic enzyme inhibitor and markedly reduces the metabolism of lamotrigine and rufinamide, so that titration rates and target dose of these latter medications is considerably reduced in the presence of valproate. If valproate is added to lamotrigine or rufinamide, the doses of these medications have to be reduced by at least 50% to prevent toxicity. Felbamate is also an important inhibitor of liver enzymes, so that doses of several AEDs have to be reduced in conjunction with its addition. Valproate and

felbamate both inhibit the clearance and cause accumulation of carbamazepine epoxide, which is a metabolite of carbamazepine responsible for some important carbamazepine toxic adverse effects. Awareness of this interaction is important since toxicity may occur in the presence of low carbamazepine levels. Carbamazepine epoxide levels must be measured upon request and sent to a central laboratory. Several AEDs are selective inhibitors of specific liver enzymes. For example, oxcarbazepine can inhibit the liver enzyme responsible for phenytoin metabolism and can produce an elevation of phenytoin level.

Another type of interaction is competition for protein binding, which can play a role in AEDs that are highly protein bound. In particular, the competition of phenytoin and valproate for protein binding is clinically relevant because therapeutic decisions are often made based on total serum levels, when it is the free levels that determine efficacy and toxicity. For example, in the presence of valproate competing for protein binding, the protein-free portion of phenytoin may rise from 10% to 30%. A phenytoin total level of 15 mcg/ml may be associated with severe toxicity because the free level is 4.5 mcg/ml, equivalent to a total level of 45 mcg/ml in an individual with the expected 10% unbound fraction. Thus when valproate and phenytoin are used together, free levels should be measured if needed for therapeutic decisions. Tiagabine is also highly protein bound, but because of its low dose and small concentration, it is less likely to affect phenytoin or valproate protein binding. In addition, tiagabine dosing is almost never based on its serum level.

Pharmacodynamic interactions do not involve a change in serum concentration of involved AEDs. They are most often related to the additive toxicity of AEDs that have the same mechanism of action. Pharmacodynamic interactions are often seen when combining AEDs that act on the sodium channel. For example, dizziness, blurred vision, diplopia, and unsteadiness are often seen when combining lamotrigine, lacosamide, carbamazepine, or oxcarbazepine. Thus mechanism of action is currently more relevant to tolerability than to efficacy of AEDs.

AED–non-AED Interactions

Interactions between AED and non-AED medications are potentially bidirectional and are most likely with the oldest AEDs. The enzyme-inducing AEDs may reduce the efficacy of many medications metabolized by the liver, such as warfarin, oral contraceptives, many chemotherapeutic agents, etc. Similarly, AED levels are affected by inducers or inhibitors of their metabolism. Carbamazepine and phenytoin levels can be elevated by many non-AED medications. The long list of agents that inhibit carbamazepine metabolism and result in carbamazepine accumulation includes cimetidine, diltiazem, erythromycin, clarithromycin, fluoxetine, isoniazid, propoxyphene, ketoconazole (and related agents), verapamil, and grapefruit juice. Oxcarbazepine, which is related to carbamazepine, is not subject to this type of interaction.

One important interaction is between estrogen, an inducer of glucuronidation, and AEDs that are metabolized by glucuronidation. Lamotrigine is the most susceptible, but valproate and oxcarbazepine are also affected to a lesser degree. Estrogen-containing oral contraceptives can reduce the lamotrigine serum level considerably, with associated increase in seizure frequency.

Success of AED Therapy

Effectiveness of medical therapy is strongly dependent on epilepsy syndrome and underlying pathology. Patients with idiopathic generalized epilepsy are much more likely to have complete seizure control than patients with partial epilepsy or symptomatic generalized epilepsy. For those with partial epilepsy, specific lesions such as hippocampal sclerosis or dual pathology are associated with a lower chance of seizure control.

Drug-resistant Epilepsy

Despite the proliferation of AEDs, approximately one-third of patients with epilepsy have persistent seizures (Kwan and Brodie, 2000a). Early response to treatment is an important predictor of drug resistance. Patients started on a first monotherapy trial have a roughly 50% chance of seizure freedom. If the first AED is failed due to side effects, the chance of seizure freedom with next monotherapy remains roughly 50%. However, if the first drug is failed due to lack of efficacy, the chance of the second drug achieving total seizure control becomes much less, approximately 11%. After failure of two AEDs, few patients become seizure-free in the long term, whether with a third monotherapy or with combination therapy. One study that related the chances of seizure control to the number of failed AEDs found 0% of seizure control after failure of 6 or 7 AEDs (Schiller and Najjar, 2008).

Definition of Drug-resistance

What failed treatment is sufficient for the patient to qualify as drug-resistant? The international League Against Epilepsy (ILAE) defined drug resistance as “failure of adequate trials of two tolerated, appropriately chosen and used anti-epileptic drug schedules (whether as monotherapy or in combination) to achieve sustained seizure freedom” (Kwan et al., 2010). Failure of an AED must be because of lack of efficacy and not intolerance. Epilepsy cannot be considered drug resistant if the AED is under-dosed or inappropriate for seizure type, or if the diagnosis of epilepsy is wrong (e.g., non-epileptic events).

Management Options for Drug-Resistant Epilepsy

Patients with drug-resistant epilepsy should have a reevaluation of the diagnosis. As always, the possibility of a diagnosis other than epilepsy should be considered when seizures do not respond to appropriate medications. The most common alternative diagnoses are psychogenic non-epileptic events and syncope. If the diagnosis of epilepsy is confirmed, evaluation for epilepsy surgery is warranted. Epilepsy surgery is appropriate if the patient has a surgically remediable syndrome with a high chance of complete seizure freedom. Examples of “surgically remediable syndromes” include epilepsy with unilateral hippocampal sclerosis and epilepsy with a well-defined small epileptogenic lesion such as cavernous malformation or benign tumor. For these patients, the chances of seizure freedom with epilepsy surgery are approximately 70%, which is much better than could be expected with any subsequent planned medication trial.

Patients who do not have a surgically remediable syndrome should have trials of additional AEDs, most probably combination therapies. However, dietary therapy and vagus nerve stimulation can be considered in individuals who are tired of ineffective AED therapies or are experiencing adverse effects from ineffective therapies. Vagal nerve stimulation (VNS) should not be implanted without first confirming the diagnosis of epilepsy; a considerable number of patients subjected to this procedure have non-epileptic events, and we must be extra vigilant to confirm the epilepsy diagnosis.

If a patient is not an optimal candidate for epilepsy surgery, trials of additional AEDs alone or in combination are appropriate before consideration of a surgical procedure that has a lower yield or that is palliative. An algorithm for identifying and managing drug-resistant epilepsy is provided in Figure **7-2**.

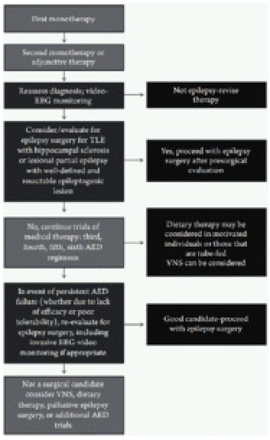


Figure 7-2:

Discontinuation of Medical Therapy

When patients enter into long-term remission, discontinuation of AED therapy may be considered in some individuals. However, it is not possible to determine if the remission will persist after medication withdrawal. While there are indicators to help predict successful AED withdrawal, there is no way to be absolutely sure that seizures will not recur. When deciding to withdraw medications, one must consider both the consequences of seizure recurrence (loss of driving privileges, risk to employment, possibility that seizures may be harder to control after recurrence) and the benefit of eliminating medication side effects and medication cost.

Children have a lower risk of seizure recurrence than adults, in general, although it depends on seizure type and etiology. This means that a trial of AED withdrawal can be considered sooner in children (1–2 years of seizure freedom) than in adults (4–5 years of seizure freedom).

AED withdrawal is more likely to be successful in:

- Patients with idiopathic epilepsy as compared to those with symptomatic epilepsy;
- Patients with epilepsy onset in adolescence as compared to epilepsy starting in childhood;
- Patients with a normal EEG as compared to those with abnormal EEG;
- Patients with partial seizures who became seizure-free quickly as compared to those who needed more than 5 years to become seizure-free;
- Adults with shorter duration of active epilepsy and a longer duration of seizure remission as opposed to adults with longer duration of active epilepsy and shorter seizure remission;
- Patients with normal psychiatric examination as compared to those with abnormal psychiatric examination;
- Patients with normal IQ as compared to those with IQ less than 70;
- Patients with normal MRI as compared to patients with MRI showing hippocampal sclerosis.

Abrupt discontinuation of AEDs is never a good idea. Severe seizures may occur during withdrawal of some AEDs, particularly benzodiazepines, carbamazepine, and oxcarbazepine. It is generally best to withdraw medications slowly.

Non-medical Treatment Options for Epilepsy

Partial epilepsies are much more likely than generalized epilepsies to be drug-resistant. These patients are the most likely to benefit from surgical therapy. Surgical approaches include temporal lobectomy, selective amygdalohippocampectomy, lesionectomy, hemispherectomy, multiple subpial transection, and corpus callosotomy.

Patients with generalized epilepsy are usually not candidates for resective (curative) surgical therapy. However, some non-pharmacological treatments can be helpful. Dietary therapy is an effective treatment for patients able to comply with this therapy. Vagal nerve stimulation (VNS) has been used mainly for partial onset seizures, but there is evidence to suggest that VNS can be helpful for idiopathic and symptomatic generalized epilepsies.

Surgical Treatment of Epilepsy

When to Do Surgery

Failure of medical therapy is an indication for consideration of epilepsy surgery. Generally, medical therapy is considered to have failed if there is no seizure control by two appropriate and tolerated drugs used at therapeutic doses. In actuality, most patients have failed many more AEDs by the time they present for epilepsy surgery evaluation. Evaluation for epilepsy surgery is not appropriate for patients who are non-compliant with medications and have not truly failed medical therapy. Evaluation for epilepsy surgery should only be for patients with disabling seizures; it should not be pursued in patients who have subjective simple partial seizures as their only seizure type.

Presurgical Evaluation and Planning

Detailed presurgical evaluation should be performed in specialized epilepsy centers with trained personnel, equipment, and experience in epilepsy surgery. Good results are largely the product of good subject selection. The best candidates for epilepsy surgery are subjects with temporal lobe epilepsy due to hippocampal sclerosis and patients with partial epilepsy and an underlying focal epileptogenic lesion.

The presurgical evaluation aims to:

- Localize the epileptogenic zone. The epileptogenic zone is defined as the zone whose resection is necessary and sufficient to eliminate seizures. It cannot be directly measured. Much of the extensive presurgical evaluation is an attempt to make the best estimate of this zone. The tests available to us in the presurgical evaluation measure other “zones” that can help estimate the epileptogenic zone (see Table 7-10)
- Determine if surgery puts any cerebral functions at risk.
- Identify patients who need additional testing, including invasive EEG, either because the epileptogenic zone is not well-defined or because eloquent cortex may be at risk

from surgery.

Table 7-10 Terms for Regions Pertaining to Localization of the Epileptogenic Zone, and Tests That Help Identify These Regions

Zone	*Significance*	*Tests that define zone*
Ictal onset zone or pacemaker zone	Zone in which seizures are originating. This zone is always contained in the epileptogenic zone, but may be smaller than the epileptogenic zone.	Ictal EEG onset; ictal SPECT
Epileptogenic lesion	Lesion causing epilepsy; some lesions are unlikely to be epileptogenic (for example, arachnoid cyst or venous angioma). Lesions may be multiple.	MRI; etiologic factors, age at risk factor/injury may suggest association with specific pathology
Irritative zone	Zone in which interictal epileptiform discharges originate. This is often larger than the epileptogenic zone	Interictal epileptiform discharges on EEG or MEG
Symptomatogenic zone	Zone that produces the first ictal clinical manifestations. This may be within or outside the first brain region along the path of seizure propagation to produce signs and symptoms.	Seizure description; analysis of seizure semiology recorded on video
Functional deficit zone	Zone responsible for functional deficits. Functional deficit can vary depending on test used. Using certain tests such as FDG, it can be much larger than the epileptogenic zone.	Physical examination; interictal slow activity or attenuation on EEG; PET; neuropsychological testing; Wada test

The presurgical evaluation always includes video EEG monitoring (which records interictal and ictal EEG and video of clinical seizures) and magnetic resonance imaging (MRI). MRI cannot be performed on patients with some implanted devices such as automated implantable cardioverter-defibrillator (AICD) and pacemakers. If MRI cannot be done, state-of-the-art brain CT (computed tomography) can show most large structural lesions. However, brain CT usually misses important lesions such as hippocampal sclerosis, cortical dysplasia, and small basal temporal mass lesions (due to bone streak artifact).

Other tests that are commonly included in the presurgical evaluation are positron emission tomography (PET) with fluorodeoxyglucose (FDG) and neuropsychological testing. A Wada test is indicated for patients with temporal lobe epilepsy who may require resection of the hippocampus. The Wada test may be skipped if there is right hippocampal sclerosis. In complex cases where localization is not clear, additional testing may include ictal single photon emission computed tomography (SPECT), magnetoencephalography (MEG), and invasive EEG with implanted intracranial electrodes (see Figure **7-3**). Figures **7-4** though **7-8** identify the elements of the presurgical evaluation in a few scenarios.

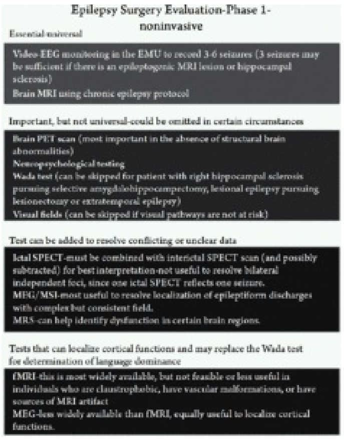


Figure 7-3:

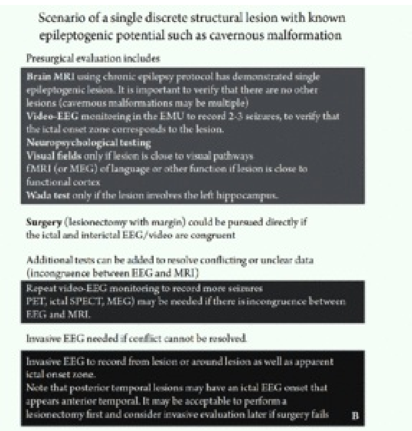
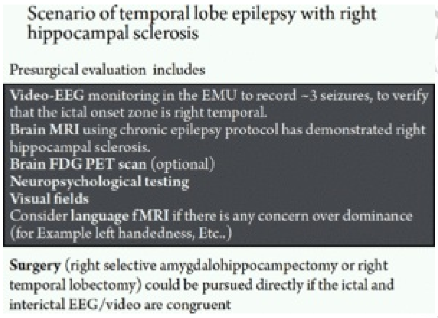


Figure 7-4:



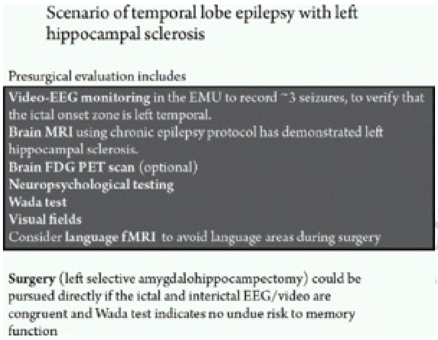
Scenario of temporal lobe epilepsy with right hippocampal sclerosis

Presurgical evaluation includes

Video-EEG monitoring in the EMU to record ~3 seizures, to verify that the ictal onset zone is right temporal.
Brain MRI using chronic epilepsy protocol has demonstrated right hippocampal sclerosis.
Brain FDG PET scan (optional)
Neuropsychological testing
Visual fields
Consider **language fMRI** if there is any concern over dominance (for Example left handedness, Etc..)

Surgery (right selective amygdalohippocampectomy or right temporal lobectomy) could be pursued directly if the ictal and interictal EEG/video are congruent

Figure 7-5:



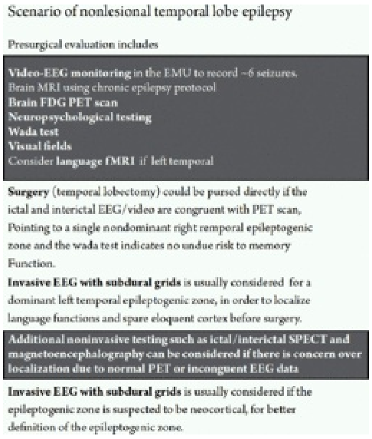
Scenario of temporal lobe epilepsy with left hippocampal sclerosis

Presurgical evaluation includes

Video-EEG monitoring in the EMU to record ~3 seizures, to verify that the ictal onset zone is left temporal.
Brain MRI using chronic epilepsy protocol has demonstrated left hippocampal sclerosis.
Brain FDG PET scan (optional)
Neuropsychological testing
Wada test
Visual fields
Consider **language fMRI** to avoid language areas during surgery

Surgery (left selective amygdalohippocampectomy) could be pursued directly if the ictal and interictal EEG/video are congruent and Wada test indicates no undue risk to memory function

Figure 7-6:



Scenario of nonlesional temporal lobe epilepsy

Presurgical evaluation includes

Video-EEG monitoring in the EMU to record ~6 seizures.
Brain MRI using chronic epilepsy protocol
Brain FDG PET scan
Neuropsychological testing
Wada test
Visual fields
Consider **language fMRI** if left temporal

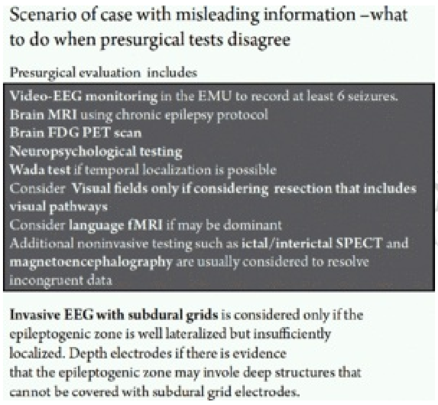
Surgery (temporal lobectomy) could be pursed directly if the ictal and interictal EEG/video are congruent with PET scan, Pointing to a single nondominant right remporal epileptogenic zone and the wada test indicates no undue risk to memory Function.

Invasive EEG with subdural grids is usually considered for a dominant left temporal epileptogenic zone, in order to localize language functions and spare eloquent cortex before surgery.

Additional noninvasive testing such as ictal/interictal SPECT and magnetoencephalography can be considered if there is concern over localization due to normal PET or incongruent EEG data

Invasive EEG with subdural grids is usally considered if the epileptogenic zone is suspected to be neocortical, for better definition of the epileptogenic zone.

Figure 7-7:



Scenario of case with misleading information –what to do when presurgical tests disagree

Presurgical evaluation includes

Video-EEG monitoring in the EMU to record at least 6 seizures.
Brain MRI using chronic epilepsy protocol
Brain FDG PET scan
Neuropsychological testing
Wada test if temporal localization is possible
Consider **Visual fields only if considering resection that includes visual pathways**
Consider **language fMRI** if may be dominant
Additional noninvasive testing such as **ictal/interictal SPECT** and **magnetoencephalography** are usually considered to resolve incongruent data

Invasive EEG with subdural grids is considered only if the epileptogenic zone is well lateralized but insufficiently localized. Depth electrodes if there is evidence that the epileptogenic zone may invole deep structures that cannot be covered with subdural grid electrodes.

Figure 7-8:

When eloquent cortex may be at risk from epilepsy surgery, localization of cortical functions is indicated (see Table 7-11). Non-invasive testing should be obtained first, and may be sufficient. However, Wada test may be needed if localization of memory is indicated, and electrical stimulation mapping may be necessary if it seems that eloquent cortex is at risk. Electrical stimulation mapping can be intraoperative (during awake surgery) or extraoperative (involving electrical stimulation and evoked potential recordings

from implanted subdural electrodes).

Table 7-11 Most Commonly Used Localization Techniques			
Technique	***Cortical functions reliably tested***	***Advantages***	***Disadvantages***
fMRI	Motor Sensory Language	Widely availableNon-invasive, safe	Indirect assessment of hemodynamic effect of activation (may be misleading in the presence of an arteriovenous malformation)Difficult to dissociate true activations from spurious onesIdentifies areas activated by task, not areas necessary for taskNot possible in patients who are claustrophobic, restless, have metal in head
MEG	Motor Sensory Language	Direct assessment of physiologic effect of activation Non-invasive, safe	Not widely available Expensive
Wada test	Language Memory	Identifies dominance for language and risks to memory function	Test of lateralization, not localization Invasive; has risks and discomforts
Extra-operative electrical stimulation	Motor Sensory Language	Identifies regions necessary for function Unlimited time	Invasive Requires additional surgery for implantation
Intraoperative electrical stimulation	Motor Sensory Language	Identifies regions necessary for certain functions	Discomfort Limited time and repertoire in operating room

After the epileptogenic zone has been localized, the appropriate surgery depends on its location, relationship to eloquent cortex, and the presumed underlying pathology (see Figure **7-9**). Invasive EEG recordings may be needed when the localization of the epileptogenic zone is not confident after non-invasive evaluation. This can be pursued only if there is a hypothesis regarding the localization.

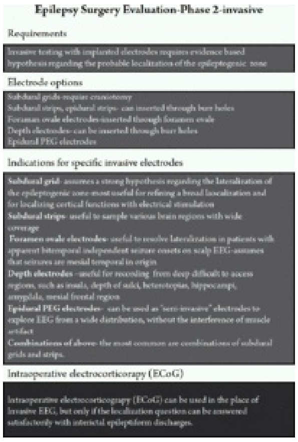


Figure 7-9:

Surgical Procedures

Surgical procedures are summarized in Table 7-12.

Table 7-12 Modalities of Surgical Therapy and Their Indications	
Modality	***Indication***
Lesionectomy	Focal lesion associated with single epileptogenic zone; in some cases the resection must include surrounding brain tissue (for example hemosiderin-stained tissue surrounding a cavernous malformation)
Temporal lobectomy	Well-localized temporal lobe focus, particularly non-dominant. This is most appropriate for non-lesional temporal lobe epilepsy when it is not known if the epileptogenic zone is mesial or lateral temporal
Selective amygdalohippocampectomy	Well-localized mesial temporal focus, particularly if associated with hippocampal sclerosis This was reserved for dominant foci, but no longer so
Tailored neocortical resection	Localized neocortical epileptogenic zone
Multilobar resection	Epileptogenic zone involves more than one lobe in one hemisphere
Hemispherectomy, hemispherotomy	Well-lateralized widespread epileptogenic zone and severe associated or anticipated motor deficit (ex: Rasmussen syndrome); if there are no independent finger movements, no significant worsening in motor function will be expected in the long term
Multiple subpial transections	Neocortical epileptogenic zone well-localized over functional (eloquent) cortex Most often used with motor, sensory or language cortex May be combined with resection
Corpus callosotomy	Palliative surgery that can be useful if the dominant seizure manifestations require rapid spread to the opposite hemisphere (for example, drop attacks). This surgery does not usually eliminate seizures, but may eliminate some debilitating manifestations such as falls.

Outcomes of Surgery

The outcome of epilepsy surgery depends on careful selection of patients and thoughtful localization of the epileptogenic zone. Epilepsy surgery can be very effective in certain groups of patients. Patients with mesial temporal lobe epilepsy generally fare better than patients with neocortical foci, and patients with small well-defined epileptogenic lesions fare better than those without lesion. Up to two-thirds of patients with mesial temporal lobe epilepsy are seizure-free at 2 years [Spencer et al., 2005]. While neocortical epilepsy has a lower response rate, it is still about 50% (Cascino et al., 1993). Other improvements besides seizure control include improved quality of life. However, epilepsy surgery also has risks, particularly verbal memory loss after dominant temporal lobe epilepsy surgery.

AED Management after Surgery

AED therapy is usually continued for at least 1 to 2 years after surgery. However, the AED regimen can be simplified and dose could be reduced in seizure-free patients. However, there is a risk of seizure recurrence after AED withdrawal. Such recurrence is less common after temporal lobe surgery for mesial temporal lobe epilepsy than surgery for neocortical epilepsy. It is also less common in children than adults. In fact, recurrence is predicted by older age at surgery and longer duration of epilepsy before surgery. Recurrent seizures may be harder to control in patients taken off AEDs after neocortical epilepsy surgery than after mesial temporal lobe epilepsy surgery.

Vagus Nerve Stimulation (VNS)

VNS is approved for adjunctive therapy for partial onset seizures in adults and adolescents 12 years of age and older (VNS Study Group, 1995). In addition, there is more recent approval for selected patients with refractory depression. Improvement in seizure control with VNS seems to increase over time. However, less than 10% are seizure-free. Because of the greater chance of seizure freedom with epilepsy surgery, patients are advised to consider it first if they are felt to be good candidates. There are reports of VNS being helpful in patients with refractory generalized epilepsy, although this is not an FDA-approved indication. As with many epilepsy therapies, VNS was tested in and approved for partial-onset seizures, but its clinical utility extends beyond FDA indications.

The electrodes are placed on the left vagus nerve and the stimulator is usually placed subcutaneously beneath the left clavicle. The stimulator settings are adjusted as needed based on seizure control and adverse effects. The default stimulation cycle is stimulation for 30 seconds followed by 5 minutes of no stimulation. Adjustment usually involves increasing the current intensity, but other parameters can also be adjusted (see Figure **7-10**).

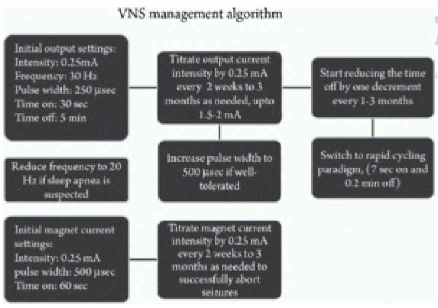


Figure 7-10:

In addition to cyclical stimulation, single VNS stimulation cycles can be generated on demand with magnet activation. The magnet-activated current can be programmed with different parameters from the recurrent output current. Patients can initiate on-demand stimulation with the magnet if they experience an aura, or a family member or caregiver can initiate the on-demand stimulation at the beginning of a seizure. Magnet activation is more likely to be helpful at the onset of a seizure and less likely to help after the seizure has progressed. In addition, the magnet can turn the stimulator off by holding it or taping it over the stimulator.

One VNS side effect to be expected is voice change or hoarseness. This improves over time. Individuals who sing or speak in public may want to turn off the stimulator temporarily during performances (by taping a magnet over it).

Dietary Treatment of Epilepsy

Dietary therapy, which was popular many years ago, was often forgotten during the explosion of newer AEDs, but has regained some interest with the realization that the new AEDs are not the miracle drugs we might have hoped for.

Ketogenic Diet

Ketogenic diet is a high-fat low-carbohydrate diet with some sustained caloric restriction. It is often initiated with fasting. This diet has been shown to be effective for a substantial minority of patients, with about 10% seizure-free and 40–50% or greater reduction in seizure frequency (Vining et al., 1998). These results are remarkable since this diet is tried in patients who have failed most available therapies, and the ketogenic diet should be considered in the armamentarium of the neurologist. Young children are more likely to benefit than older children and adults, partly because of better compliance.

The ketogenic diet can be used for patients with refractory seizures of almost any type, especially if there is difficulty with tolerating seizure medications. Particular types of epilepsy that may respond better than others include epilepsy due to glucose transporter deficiency or pyruvate dehydrogenase deficiency, myoclonic-astatic epilepsy, tuberous sclerosis, or infantile spasms. Ketogenic diet should not be used in patients with mitochondrial disorders, pyruvate carboxylase deficiency, and β-oxidation defects.

Difficulty maintaining compliance is the main limitation of the ketogenic diet. Hence it is most useful in individuals for whom compliance is not an issue, for example tube-fed subjects or infants receiving formula. Other diets have been explored to improve compliance with dietary therapy.

Modified Atkins Diet

The modified Atkins diet is a response to difficulty tolerating the ketogenic diet. The diet is also low carbohydrate, but with no restriction in proteins, fats, or calories.

This diet has been used for a variety of epilepsies with reported success in children not very different from the ketogenic diet (Chen and Kossoff, 2012). This is better tolerated and with less adverse effects than the ketogenic diet and may be considered as an alternative for select patients, particularly adults.

Low Glycemic Index Diet

The low glycemic index diet is another low- carbohydrate diet that is a bit more permissive, in that it allows carbohydrates with low glycemic index (meaning they will not raise blood glucose). It has also shown seizure reduction in children with refractory seizures (Muzykewicz et al., 2009).

Immune Therapies Directed to the Underlying Pathology

There is increasing recognition that some forms of epilepsy are immune in nature, and immunological therapy may be effective in these disorders. Steroids may be particularly effective in epilepsy associated with Hashimotos's encephalopathy, also referred to as steroid-responsive encephalopathy with anti-thyroid antibodies (Castillo et al., 2006). Steroid pulse therapy (intravenous methylprednisolone 0.5–1 gram per day for 3–5 days) is effective in eliminating seizures in patients with limbic encephalitis and antibodies against voltage-gated potassium channels- LGI1 complex (Malter et al., 2010). There is a suggestion that inflammation may play a role in chronic epilepsy, even when the initial underlying cause is not autoimmune, and immune therapies are in early testing for drug-resistant epilepsy.

Investigational Approaches to Management

New approaches are needed to further improve seizure control for patients with refractory epilepsy. Investigational approaches are both medical and surgical. Table 7-13 lists some of the promising therapies.

Table 7-13 Select Investigational Therapies for Epilepsy

Therapeutic approach	*Description*
Thalamic stimulation	Bilateral stimulation of the anterior thalamus may be promising with more than half the patients experiencing at least a 50% seizure reduction (Fisher et al., 2010; Jobst et al., 2010a). This stimulation is performed in steady state with settings adjusted to achieve optimal control. If FDA-approved, this treatment will most likely be used for patients who are not candidates for epilepsy surgery and have failed most commercially available therapies including VNS.
Responsive cortical stimulation	This treatment modality is based on the finding that an electrical stimulus can abort a seizure if delivered very shortly after onset. Responsive cortical stimulation requires prior localization of the epileptogenic zone or zones. Candidates for this type of stimulation most probably will have bilateral independent seizure foci or an epileptogenic zone that overlaps with eloquent cortex, thus precluding surgical therapy. The stimulating device also records. Stimulation is delivered on demand through implanted depth or subdural strip electrodes when an electrographic seizure onset is first detected. In the pivotal clinical trial more than 40% of patients had at least 50% seizure reduction (Morrell MJ; RNS System in Epilepsy Study Group. Responsive cortical stimulation for the treatment of medically intractable partial epilepsy. Neurology. 2011;77:1295–304).
Trigeminal nerve stimulation	In this non-invasive treatment modality, ophthalmic and supratrochlear branches of the trigeminal nerve are stimulated bilaterally transcutaneously. A recent study provided evidence of efficacy and safety in drug-resistant partial epilepsy (Degiorgio et al., 2013)
Radiosurgery	Radiosurgery involves radiation beams precisely directed to a target from different angles with the help of a stereotactic frame that immobilizes the head. It is a useful treatment modality for epilepsy associated with small hypothalamic hamartomas (which can be difficult to access surgically). It is also being explored for mesial temporal lobe epilepsy with hippocampal sclerosis. Studies indicate that it is an effective treatment, with more than three-quarters of patients becoming seizure-free after a latency of 1 to 2 years (Barbaro et al., 2009). If FDA approved for mesial temporal lobe epilepsy, this procedure may be useful for individuals with hippocampal sclerosis who are not willing to have standard open surgery.

Quality of Care Standards and Counseling

The American Academy of Neurology has established quality standards for evaluation and management of epilepsy. The standards are summarized in Table 7-14.

Table 7-14 Recommended Quality Measures for Epilepsy Care

Quality measure	*Where applicable*	*Description*
Seizure typesCurrent seizure frequency	All patients All visits	Document seizure types and current seizure frequency for each type
Etiology of epilepsy or epilepsy syndrome	All patients All visits	Document etiology of epilepsy or epilepsy syndrome (or specify as unknown)
EEG results	All patients All initial evaluations	Document results of at least one EEG reviewed or requested or order EEG if not previously performed
Brain MRI (or CT) results	All patients All initial evaluations	Document result of at least one MRI scan reviewed or requested or order MRI scan if not previously obtained. CT is acceptable though MRI preferred
AED side effects	All patients All visits	Document inquiry into and counseling about AED side effects
Surgical therapy consideration or referral	Patients with drug-resistant epilepsy At least every 3 years	Document that surgical therapy was considered (and referral made) in patients with drug-resistant epilepsy or why it is not appropriate
Counseling about safety issues	All patients At least once a year	Document counseling about epilepsy-specific safety issues relevant to age, seizure type, occupation and leisure activities (e.g., injury prevention, burns, driving restrictions, or bathing)
Counseling for women of childbearing potential	Female patients of childbearing potential At least once a year	Document counseling about how epilepsy treatments may affect contraception, pregnancy, and the fetus

For each of these standards, it is important to document consideration and discussion. The quality standards are particularly relevant to patients with drug-resistant epilepsy. They ascertain that the treating physician will reconsider the epilepsy diagnosis and will attend to new features that might alter treatment.

Discussion with the patient should include sufficient feedback to ensure that the patient or caregiver understands the issues. All questions are ideally answered. Documentation of these discussions is key. Not only does this ensure that we are reminded in future visits when the issues were discussed, but good documentation affords some liability protection.

Counseling

Counseling for patients with epilepsy is complex, with specific recommendations depending on the specific clinical issue.

Driving and Other Safety Issues

Common sense dictates that patients who have seizures, arrhythmia with syncope, and other medical conditions that interfere with mental activities and neurologic functioning should not be driving, working with heavy moving machinery, working at unprotected heights, or performing other risky duties. Driving is only one part of the discussion of safety.

The period of seizure-freedom before a patient can drive varies between states, from 3 months to 1 year. Also, there are differences between states concerning whether the patient must surrender the driver's license or just not drive, and whether the physician must report patients with uncontrolled seizures to the state. So physicians must be familiar with laws in their state. In addition, some businesses have restrictions on activities that are more stringent than the state law for driving.

Some states allow exceptions to the driving restriction for people with purely nocturnal seizures, or simple partial seizures that do not interfere with ability to drive (for example, isolated auras) or patients with long auras that allow them time to get off the road before the altered awareness. These leniencies are not without risk and merit careful discussion between clinician and patient and total awareness of the laws in their locale. The pattern of purely nocturnal sleep-related seizures or pure simple partial seizures must have been established for at least 6 months in order to remove restrictions.

Recreational activities such as swimming, hiking, and climbing have risks to both people with epilepsy and those without. In general, risky activities become riskier in the presence of epilepsy. A decision has to be made individually, considering a number of factors including patient age, type of seizures, frequency of seizures, and neurologic functioning.

Sudden Unexplained Death in Epilepsy (SUDEP)

The risk of sudden unexplained death is increased in epilepsy, more than 20 times that of controls when considering the age group of 20–40 years. SUDEP is most often in the setting of a seizure, usually a generalized tonic-clonic seizure. There is evidence that complete seizure control essentially eliminates the risk of SUDEP. Breakthrough seizures related to poor compliance are a risk factor for SUDEP. Most neurologists do not discuss SUDEP with their patients so as not to cause undue anxiety. However, bereaved family members feel that patients should have been counseled about SUDEP risk, and that fear of SUDEP would have improved compliance. Physicians should consider counseling select patients who are at high risk of SUDEP due to frequent uncontrolled generalized tonic-clonic seizures. Patients with mild seizures and patients with well-controlled epilepsy need not be educated about SUDEP.

Inheritance

Many epilepsies have a genetic basis or a genetic component. Genetic tests are available for only a few forms of epilepsy. While there are few instances where epilepsy genetics predict AED efficacy, obtaining a genetic diagnosis can be very valuable for closure and to avoid unnecessary continued search for an etiology. An underlying genetic etiology is often evident without specific genetic testing. Most commonly, patients are interested to know the risk of epilepsy in their children, or parents may want to know the risk of having another affected child. Most genetic epilepsy syndromes, such as juvenile myoclonic epilepsy, are polygenic and the risk of epilepsy in a child is less than 6–7%. However, epilepsy is monogenic in some families, with higher associated risk in offspring.

Status Epilepticus

Status epilepticus is commonly encountered in a busy emergency room or neurology practice and treatment should be rapid and aggressive. Status epilepticus is defined as seizure activity continuing for 30 minutes or recurrent seizures without recovery between events. However, since there is risk of neuronal damage with increasing seizure duration, aggressive treatment is warranted and should not wait for the 30-minute definition. Acute therapy of generalized convulsive seizure activity should start within 5 minutes, based on the finding that generalized tonic-clonic activity that stops spontaneously rarely lasts longer than 2 minutes. For complex partial seizures, treatment should start after 10–15 minutes.

Convulsive status epilepticus includes status epilepticus with tonic or clonic motor manifestations, whether generalized or focal. Non-convulsive status epilepticus includes complex partial status epilepticus without tonic-clonic motor activity and absence status epilepticus. Subjective simple partial status epilepticus is usually considered separately and is often referred to as *aura continua*. Generalized convulsive status epilepticus is a medical emergency requiring immediate treatment. While non-convulsive status epilepticus is a lesser emergency, it also requires prompt therapy.

Diagnosis

EEG is performed as soon as possible on patients with suspected status epilepticus. This is for confirmation of the diagnosis, characterization of the ictal discharge pattern, and monitoring of response to treatment. Confirmation of the diagnosis is particularly important since it is common for psychogenic non-epileptic events to present as clinical status epilepticus.

Continuous EEG monitoring of patients with status epilepticus should be performed when possible. The possibility of persistent electrical seizure activity should always be considered in a patient with convulsive status epilepticus who does not wake up after motor activity stops.

In a patient without prior known epilepsy, identification of the cause of the status epilepticus usually requires imaging with MRI or CT, blood tests (glucose and electrolytes), and sometimes lumbar puncture (LP) for possibility of CNS infection. However, imaging and LP should be performed only after convulsive status epilepticus has been controlled.

Treatment

Treatment of the status epilepticus can begin before hospitalization, with paramedics administering lorazepam 2–4 mg IV or midazolam 10 mg IM (dosing for adults and children weighing more than 40 kg) (Alldredge et al., 2001; Silbergleit et al., 2012). This can stop the seizure activity in more than half of patients. Alternatively, if the patient has a history of prolonged seizures, the caregivers may administer rectal diazepam, which can be helpful even though it is FDA approved for seizure clusters rather than status epilepticus. Use of rectal diazepam before emergency room arrival was associated with shorter duration of status epilepticus, even if status was still ongoing upon arrival.

Figures **7-11a** through **7-11c** show suggested protocols for treatment of status epilepticus, based on Vanderbilt protocols. As shown in the figures, benzodiazepines and fosphenytoin are cornerstones for treatment of generalized tonic clonic status epilepticus.

Figure 7-11a:

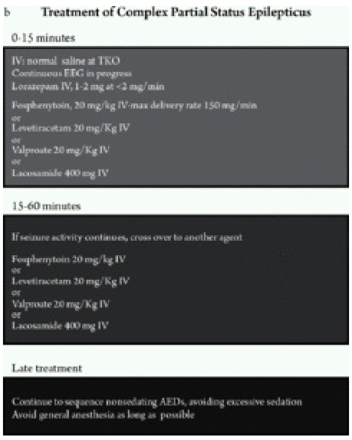


Figure 7-11b:

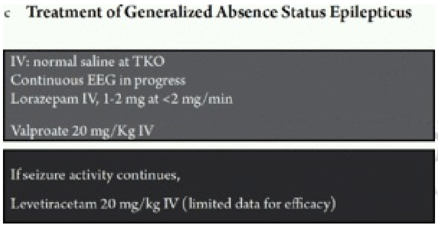


Figure 7-11c:

Complex partial status epilepticus can be treated with the same initial medications (but a lower dose of lorazepam), but if additional therapy is needed, non-sedating intravenous AEDs should be used preferentially.

Generalized absence status epilepticus can be treated with IV lorazepam and valproate.

Generalized myoclonic status epilepticus can be treated with IV lorazepam, IV valproate, and/or IV levetiracetam.

Table 7-15 Anti-epileptic drugs: How supplied.

Generic name	Brand name	How supplied
Carbamazepine	Tegretol	100 mg chewable 200 mg tablets 100 mg/5 ml suspension
	Tegretol-XR	100 mg, 200 mg, 400 mg tablets
	Carbatrol	100 mg, 200 mg, 300 mg capsules
	Generic	All of the above
Clonazepam	Klonopin (Generic is same)	0.5 mg, 1 mg or 2 mg tablets 0.125 mg, 0.25 mg, 0.5 mg, 1 mg or 2 mg orally disintegrating tablets
Divalproex	Depakote	125 mg, 250 mg, 500 mg tablets 125 mg sprinkle capsules
	Depakote ER	250 mg, 500 mg tablets
	Generic	All the above
Ethosuximide	Zarontin(Generic is same)	250 mg capsules 250 mg/5 ml oral solution
Felbamate	Felbatol(Generic is same)	400 mg and 600 mg tablets 600 mg/5 ml oral Suspension
Gabapentin	Neurontin(Generic is same)	100 mg, 300 mg, 400 mg capsules 600 mg, 800 mg tablets
Lamotrigine	Lamictal(Generic is same)	25 mg, 100 mg, 150 mg, 200 mg tablets 2 mg, 5 mg, and 25 mg chewable dispersible tablets 25 mg, 50 mg, 100 mg, 200 mg orally disintegrating tablets
	Lamictal XR	25 mg, 50 mg, 100 mg, 200 mg, 250 mg, 300 mg tablets
Levetiracetam	Keppra(Generic is same)	250 mg, 500 mg, 750 mg, 1000 mg tablets
	Keppra XR	500 mg, 750 mg tablets
Methsuximide	Celontin	150 mg, 300 mg capsules *
Oxcarbazepine	Trileptal(Generic is same))	150 mg, 300 mg, 600 mg tablets 300 mg/5 ml oral suspension
Phenobarbital	–	15 mg, 16.2 mg, 30 mg, 32.4 mg, 60 mg, 64.8 mg, 97.2 mg, 100 mg tablets 20 mg/5 ml elixir.
Phenytoin	Dilantin	100 mg and 30 mg capsules of phenytoin sodium 50 mg tablets of phenytoin (infatab) 125 mg/5ml suspension
	Phenytek	200 mg, 300 mg capsules
	Generic	100 mg, 200 mg, 300 mg capsules, 125 mg/5ml suspension
Primidone	Mysoline(Generic is same)	50 mg and 250 mg tablets
Tiagabine	Gabitril	2 mg, 4 mg, 12 mg, 16 mg tablets
Topiramate	Topamax(Generic is same)	25 mg, 50 mg, 100 mg, 200 mg tablets 15 mg, 25 mg sprinkle capsules
Valproic acid	Depakene	250 mg capsules 250 mg/ 5ml syrup
Zonisamide	Zonegran	25 mg, 100 mg capsules
	Generic	25 mg, 50 mg, 100 mg capsules

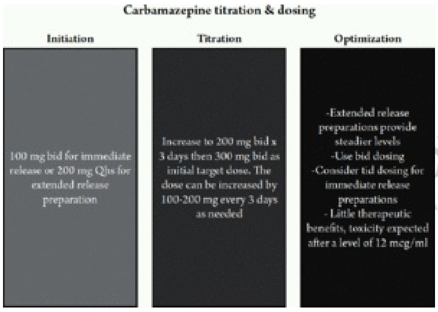
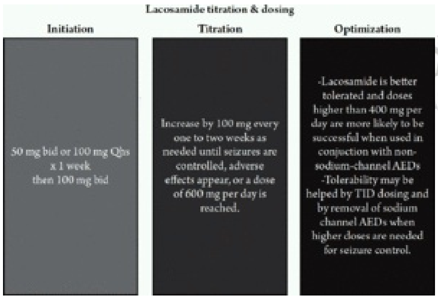


Figure 7-12:



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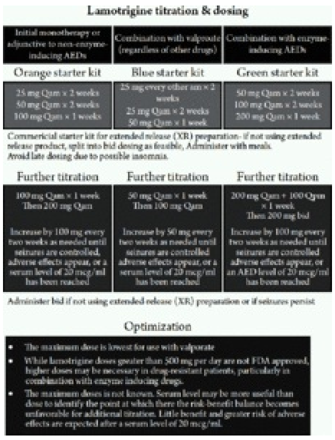

Figure 7-14:

Figure 7-15:

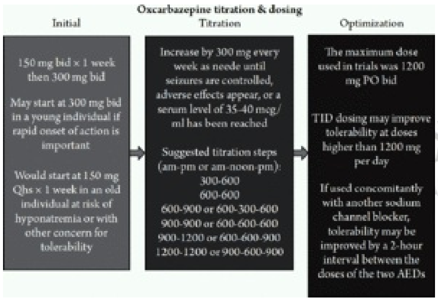

Figure 7-16:

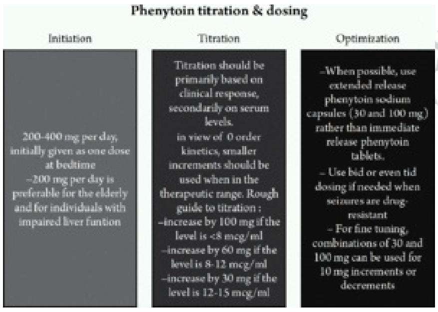

Figure 7-17:

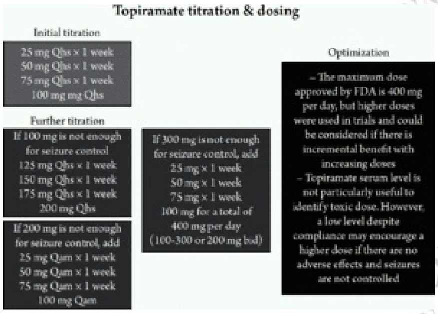

Figure 7-18:

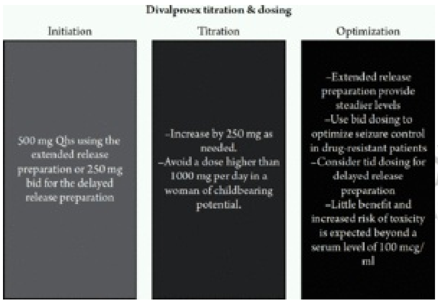

Figure 7-19:

Oxford Medicine

Atlas of EEG, Seizure Semiology, and Management

Karl E. Misulis

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Samples and Case Discussions

Chapter: Samples and Case Discussions
Author(s): Karl E Misulis
DOI: 10.1093/med/9780199985906.003.0008

EEG Stills

14 & 6 Positive Spikes—14 Hz Predominant

54-year-old male with altered mental status (Figure **8-1**). The 14 Hz positive bursts are best appreciated with the linked ear or contralateral ear reference. This benign variant is reported with increased incidence in Reye syndrome, but also other encephalopathies (Yamada et al., 1977).

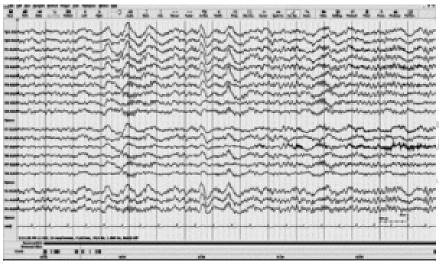


Figure 8-1:

14 & 6 Positive Spikes—6 Hz Predominant

74-year-old with generalized epilepsy (Figure **8-2**). The recording shows 6 Hz intermittent notched rhythmic activity in both temporal regions. Elsewhere the EEG recorded occasional generalized 3–4.5 Hz spike-and-wave discharges.

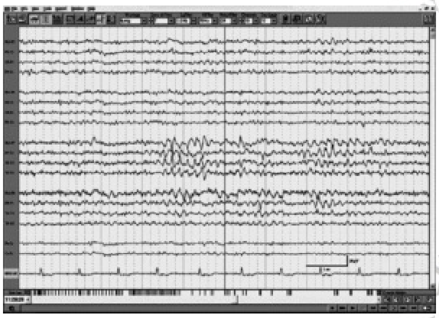


Figure 8-2:

60 Hz Electrical Artifact

60 Hz artifact at Fp1, reflecting increased impedance at that electrode (Figure **8-3**).

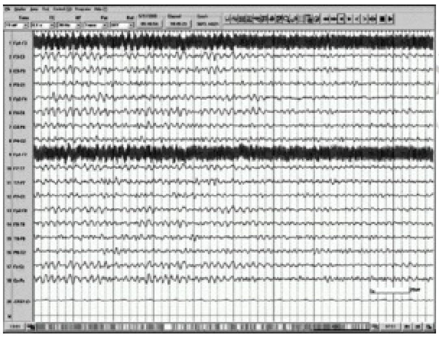


Figure 8-3:

Absence Seizure

10-year-old with episodes of spacing out and staring (Figure **8-4**). He was previously diagnosed with attention deficit hyperactivity disorder.

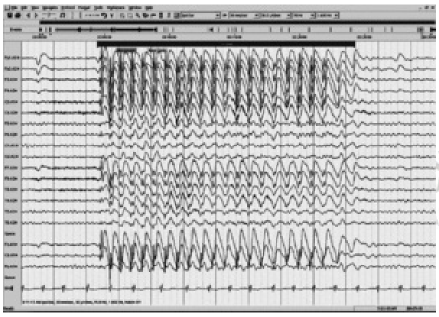


Figure 8-4:

Absence Without Spike

7-year-old girl with staring spells (Figure **8-5**). The EEG showed a burst of generalized 2.5–2 Hz delta activity associated with a delayed response to a command. This may be consistent with an absence seizure. Bursts of rhythmic delta activity without spikes have been described as a rare ictal pattern in absence seizures. However, there is a debate about the nature of such discharges brought on with hyperventilation.

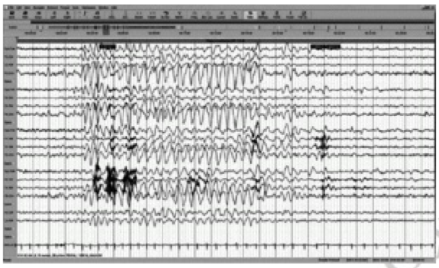


Figure 8-5:

Alpha Coma

14-year-old who had a cardiac arrest (Figure **8-6**). He was on propofol and fentanyl. Diffuse alpha-range activity is clearly abnormal.

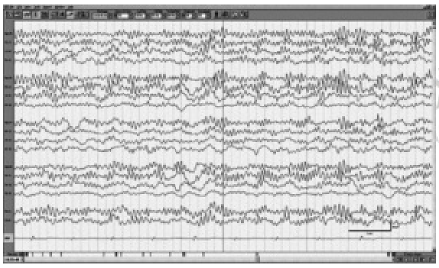


Figure 8-6:

Alpha-theta coma

38-year-old who had a cardiac arrest (Figure **8-7**). He was unresponsive to voice but had spontaneous eye opening. He had extensor posturing to stimulation. The EEG shows generalized frontally dominant alpha-theta activity, not reactive to passive eye opening and closure.

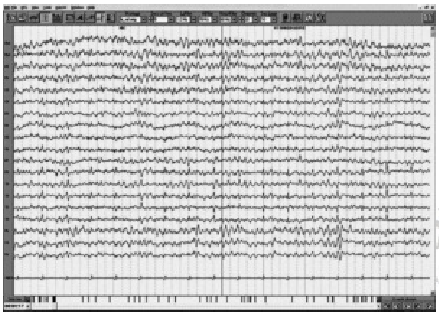


Figure 8-7:

Periodic Discharges with Anoxia

56-year-old with witnessed tonic-clonic jerking after cardiac arrest (see the series of EEGs shown in Figures **8-8a** through **8-8d**). The EEG showed continuously evolving pattern and frequency, with abrupt termination of rhythmic EEG activity with attenuation followed by periodic activity. The evolution is consistent with an ictal pattern. However, the anoxic etiology implies a poor prognosis.

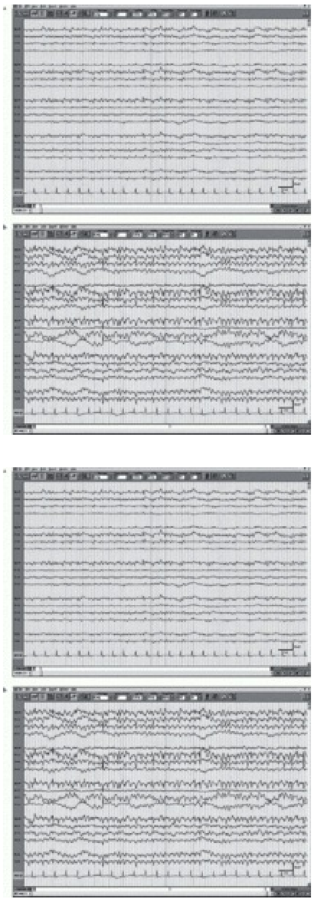


Figure 8-8:

Eye Blinks

17-year-old with anger outbursts (Figure **8-9**). Repetitive eye blinks and eye flutter may be confused with bifrontal ictal activity. Note the onset of the eye blinks after eye opening with dramatic attenuation of the posterior dominant rhythm.

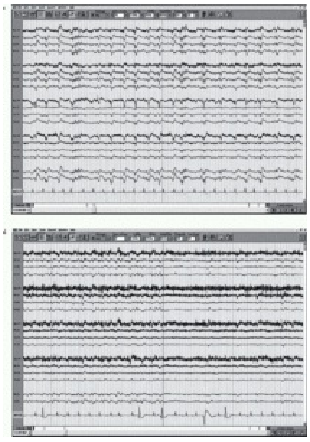


Figure 8-9:

Generalized Polyspike-and-Wave

38-year-old male with past epilepsy, extensive burn injuries, and recurrent seizures in the hospital (Figures **8-10a** and **8-10 b**). EEG showed frequent generalized polyspike-and-wave discharges consistent with generalized epilepsy.

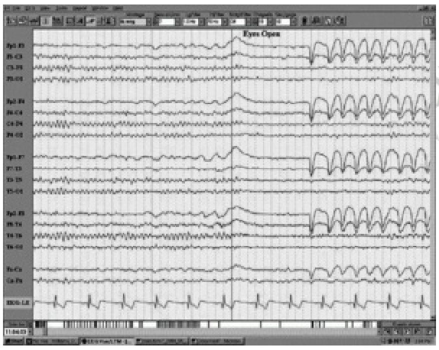


Figure 8-10:

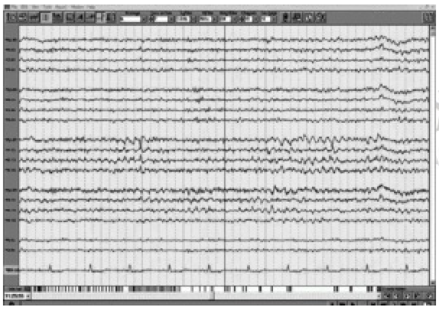
Rhythmic Midtemporal Theta of Drowsiness

Rhythmic midtemporal theta of drowsiness is seen in this otherwise normal EEG (Figure **8-11**). This can be easily misread as pathological, especially with unilateral appearance especially at onset.

Figure 8-11:

Hepatic Encephalopathy

44-year-old woman with cirrhosis with hepatic failure, and declining mental status (Figures **8-12a** through 8-12c). The semi-periodic triphasic waves had a shifting anterior-posterior predominance. Stimulation seemed to activate the discharges. Ammonia was 103 (normal range 11–35 mcmol/L).



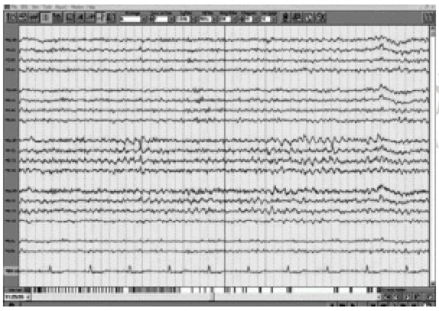


Figure 8-12:

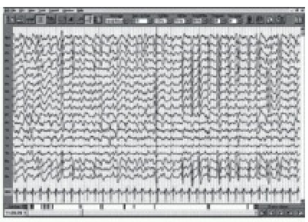
HSV Encephalitis

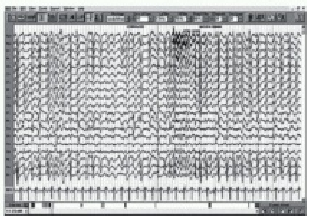
94-year-old female with HSV encephalitis. She had been having episodes of eye twitching, which in retrospect may have been small seizures, for several days. Then she had a decline in level of activity progressing to nonverbal. She was in stupor at the time of the EEG (Figure **8-13a**), which shows a disorganized and slow background with left temporal periodic discharges. MRI (Figure **8-13b**) showed a T2 hyperintense lesion of the left anterior and lateral>medial temporal lobe. She had a positive CSF test for HSV-1.

Figure 8-13:

Hyperventilation Artifact

29-year-old female with staring spells (Figures **8-14a** through **8-14c**). The patient was lying over the left side. Readjustment of head position largely eliminated the left occipital artifact (Figure **8-14c**). The EEG was normal.





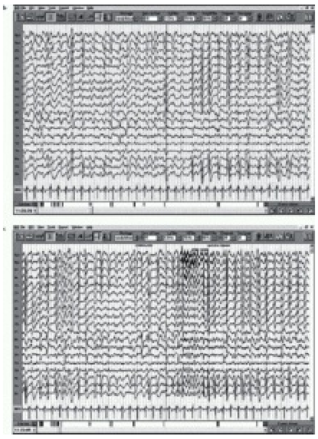


Figure 8-14:

Hypsarrhythmia

9-month-old male with prematurity and one month of epileptic spasms (Figures **8-15a** and **8-15b**). MRI was normal. The study recorded 3 clusters of infantile spasms. The associated EEG changes were high voltage slow waves with superimposed fast activity followed by 1–2 seconds of generalized attenuation. The interictal EEG showed multifocal epileptiform discharges, most often right parietal, and a chaotic high amplitude disorganized slow background with no posterior rhythm, consistent with hypsarrhythmia.

Figure 8-15:

Wicket Spikes

75-year-old woman with spells that were determined to be non-epileptic when evaluated with inpatient video EEG monitoring. Her EEG was previously interpreted by a general neurologist as showing right and left midtemporal spikes and an electrographic seizure from the left temporal area. The EEG recording in Figure **8-16** shows wicket patterns from both temporal regions, but predominant on the left. The higher voltage sharply contoured waves are components of a monorhythmic activity that waxes and wanes in its voltage, but does not evolve in frequency.

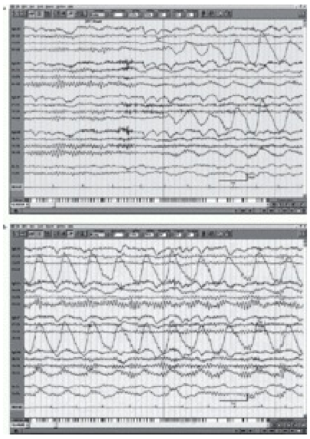


Figure 8-16:

Breach Rhythm

77-year-old man with altered mental status (Figures **8-17a** through **8-17c**). He had old right thalamic stroke. The EEG showed increased beta activity and fragments of mu rhythm at C3, suggesting breach rhythm. The CT scan confirmed the presence of a skull defect. There had been no mention of craniotomy in his hospital notes, but a search of the records determined that he had had craniotomy for placement of cortical stimulating electrode to relieve thalamic pain syndrome.

Figure 8-17b:
Bipolar Montage.

Figure 8-17c:
CT brain Showing the Left-sided Skull Defect.

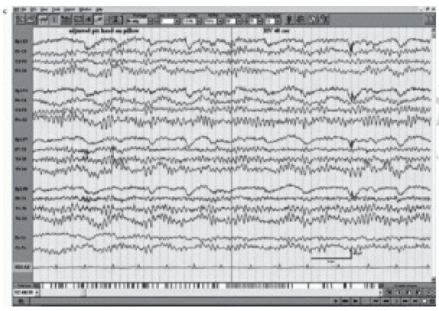


Figure 8-17:

Referential montage.

Generalized Tonic-clonic Seizures

21-year-old man with juvenile myoclonic epilepsy has generalized tonic-clonic seizures with no aura; he may stare before the motor activity (Figures **8-18a** and **8-18b**). He also has myoclonic jerks, mostly in the am. The generalized tonic-clonic seizure started with generalized, frontally dominant, polyspikes and spike-and-wave discharge initially at 9 Hz then 3–6 Hz. The activity evolved to approximately 10 Hz rhythmic activity in transition to the generalized tonic-clonic seizure.

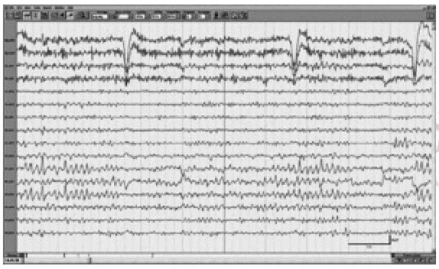


Figure 8-18:

Burst Suppression

36-year-old woman with severe closed head injury in pentobarbital coma for increased intracranial pressure (Figure **8-19**). CT showed multiple areas of intracranial hemorrhage with increasing surrounding edema. EEG showed a burst suppression pattern. The bursts consisted of generalized irregular theta and delta activity lasting 2 to 4 seconds. Suppression periods ranged between 30 seconds to 4.5 minutes by the end of the recording.

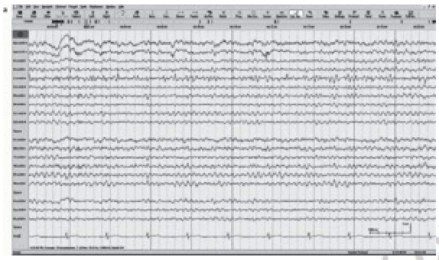


Figure 8-19:

Creutzfeldt-Jakob Disease

74-year-old man with rapidly progressive dementia (Figures **8-20a** through **8-20c**). The EEG showed intermittent left hemisphere periodic discharges activated with arousal and stimulation. The MRI shows typical increased left posterior and right frontal cortical ribbon signal on diffusion MRI images. The finding is absent in the FLAIR MRI. The autopsy confirmed the diagnosis of prion disease with the characteristics of sporadic Creutzfeldt-Jakob disease.

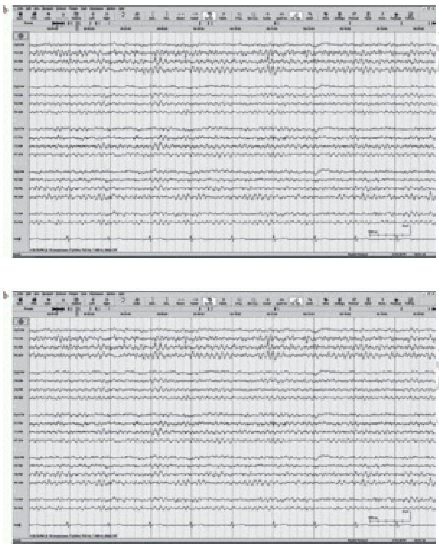


Figure 8-20:

Cough Syncope

48-year-old man with obesity and spells of unclear nature that were determined to be non-epileptic (Figures **8-21a** and **8-21b**). He had an episode of brief multifocal myoclonus and altered responsiveness after persistent cough in the setting of hyperventilation. The EEG showed generalized slow activity then generalized attenuation, followed by slow activity then recovery of normal EEG rhythms. The findings represent an episode of cough syncope.

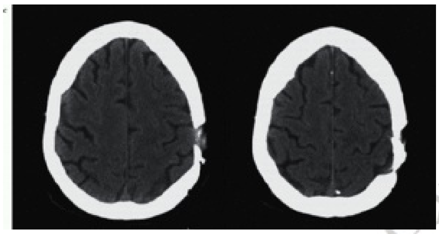


Figure 8-21:

Pentobarbital Coma

24-year-old male with severe traumatic brain injury from motorcycle accident (Figures **8-22a** and **8-22b**). CT showed right frontal intraparenchymal hemorrhage, diffuse subarachnoid hemorrhage, subdural hematoma along the falx, extensive intraventricular hemorrhage predominantly on the left, right to left midline shift, and uncal herniation. He was placed in pentobarbital coma for treatment of increased intracranial pressure. The EEG segments show the effect of deepening pentobarbital coma, with increasing duration of interburst intervals, until complete suppression.

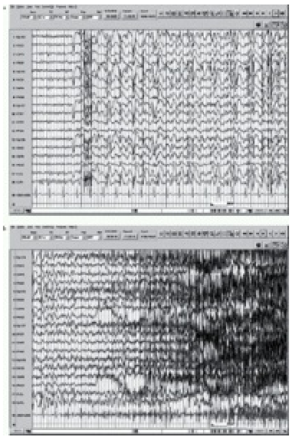


Figure 8-22:

Polymorphic Delta Activity

19-year-old man with severe traumatic brain injury, daily complex partial seizures, and occasional secondarily generalized tonic-conic seizures (Figures **8-23a** through **8-23c**). He has left hemiplegia, can only use the right arm. CT shows right frontal and right temporal encephalomalacia, diffuse enlargement of the ventricular system, and a ventriculoperitoneal shunt entering from a left parietal approach.

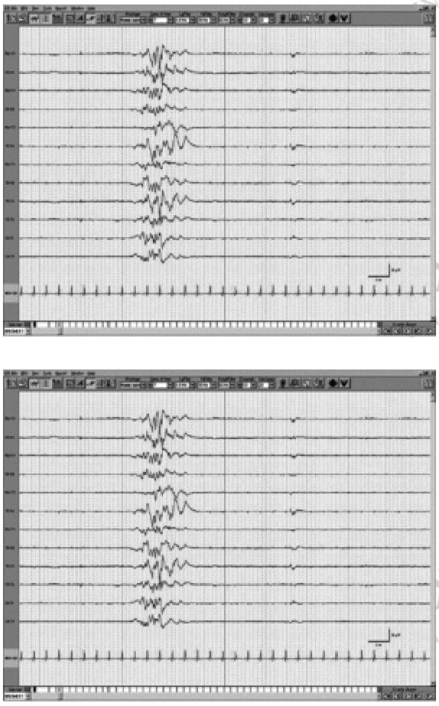


Figure 8-23:

The EEG shows polymorphic delta activity as well as a sharp wave in the right posterior quadrant, the presumed epileptogenic zone. In this case the polymorphic delta activity is more related to functional (focal epilepsy) than structural lesion.

EKG Artifact

38-year-old obese man with hypertension and hyperglycemia (Figures **8-24a** and **8-24b**). EKG artifact is most prominent with ipsilateral ear reference. It will be noted that the artifact is of opposite polarity on the two sides. It became less prominent with linked ear reference recording and longitudinal bipolar recordings.

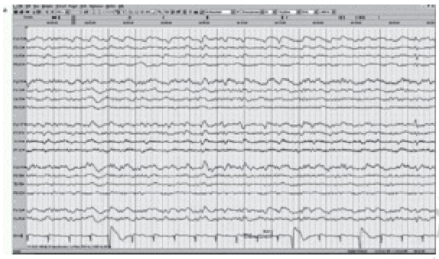


Figure 8-24:

Parkinsonism with Tremor

84-year-old man with advanced Parkinson's disease complicated by anxiety and dementia (Figures **8-25a** and **8-25b**). Examination showed bilateral resting and postural tremor, worse with stressful discussions. He also had a mild head tremor and chin tremor. EEG was obtained because of episodes of unresponsiveness. The EEG above shows tremor artifact in the left posterior head region.

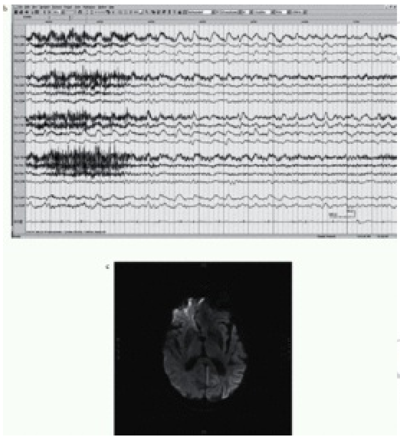


Figure 8-25:

Attenuation with Subdural Hematoma

Patient with subdural hematoma with signs on CT of acute and chronic blood (Figures **8-26a** and **8-26b**). The EEG shows attenuation over the left hemisphere. The loss of faster frequencies is evident on this side.

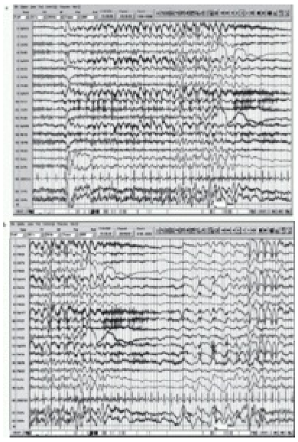


Figure 8-26:

Photic Driving Response

The patient is being evaluated for epilepsy (Figure **8-27**). During photic stimulation, a prominent photic driving response is seen. Because of the very regular activity that is

time-locked to the stimulus, and the abrupt termination at the end of photic stimulation, this should not be confused with epileptiform discharge.

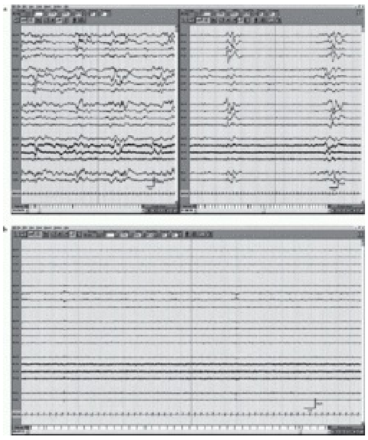


Figure 8-27:

Polymorphic Delta Activity

This is a 42-year-old woman with seizures since age 15 (Figure **8-28a**). The EEG was done one day after the police found her wandering the street in complex partial status epilepticus or postictal confusion. The EEG showed irregular delta-theta activity in the right hemisphere, with midtemporal and posterior temporal predominance. There was also attenuation of posterior dominant rhythm on the right.

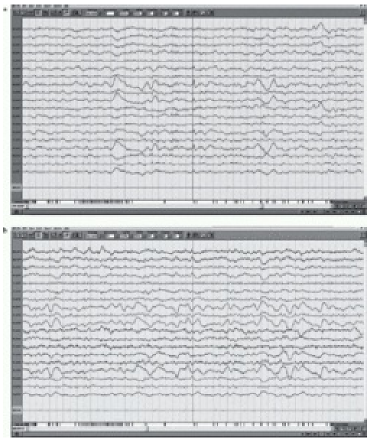


Figure 8-28:

CT brain shows right temporal encephalomalacia (Figure **8-28b**). The slowing on the EEG is likely a combination of this structural lesion plus postictal slowing.

Excess Beta Activity

An adult female is being evaluated for syncope (Figure **8-29**). This patient has excessive beta activity, which in this case was due to clonazepam, a benzodiazepine. Barbiturates also typically produce excessive beta activity. This is commented on in the report, but not interpreted as a specific abnormality.

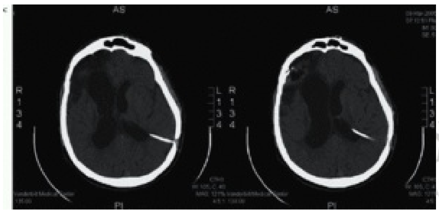


Figure 8-29:

Encephalopathy

An adult female is being evaluated for mental status changes (Figure **8-30**). The pattern shows symmetric slowing consistent with encephalopathy. She is described as being in the awake but confused state, so she is not deeply asleep. This pattern is too slow for simple drowsiness. Slowing of the background can be seen in patients with infections and multiple metabolic abnormalities, however, the findings are not specific. The interpretation of the recording should reflect the non-specific nature of the results.

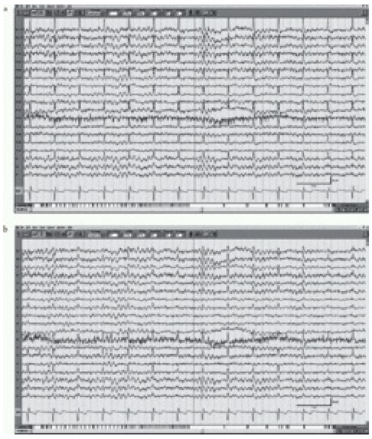


Figure 8-30:

PLEDs

An adult female is being evaluated for mental status changes associated with fever and seizures (Figure **8-31**). This EEG shows periodic lateralized epileptiform discharges (PLEDs). These are typically seen in patients with herpes encephalitis, as in this patient. However, they can also be seen with stroke and other destructive lesions. The etiology of PLEDs cannot be determined without clinical information.

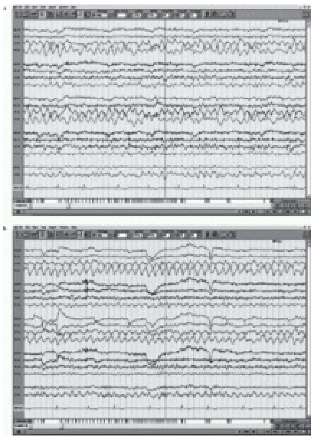


Figure 8-31:

Eye Blink

A patient being evaluated for seizures has the following EEG (Figure **8-32**). The patient is awake. Eyes open at the midpoint of the recording, as indicated by the technician's comment.

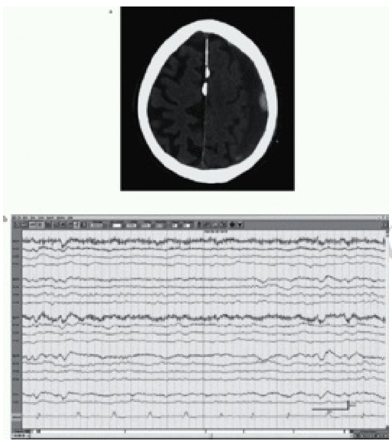


Figure 8-32:

Eye blink artifact is shown on the right side of the recording. The activity is coming from the frontal electrode leads. The activity is more stereotyped than would be seen with FIRDA. The patient is in the awake state and the localization of the activity takes it out of the realm of vertex activity. Frontal arousal rhythm is an unusual rhythmic activity seen in young children awakening from sleep, and has a different appearance.

Hypsarrhythmia

A 3-year-old male is being evaluated for seizures and developmental delay (Figure **8-33**). The following EEG is recorded.

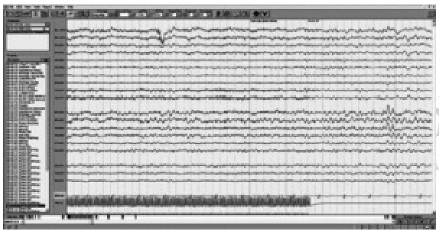


Figure 8-33:

The background is disorganized and there are high-voltage, polymorphic discharges. This is characteristic of hypsarrhythmia. Patients with hypsarrhythmia are more likely to have seizures including infantile spasms. West syndrome is the triad of infantile spasms, hypsarrhythmia, and mental retardation, although not all three of the triad have to be present for diagnosis.

Absence Seizure

A 10-year-old boy is being evaluated for seizures (Figure **8-34**). He has episodes of unresponsiveness without focal motor activity and without loss of posture. He has a normal examination. The following epoch is from his recording. The technician did not notice any behavioral correlate to the repetitive activity noted in this epoch.

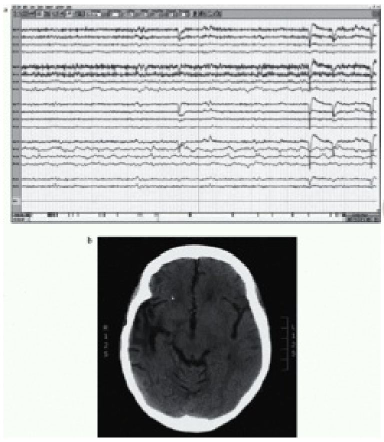


Figure 8-34:

This patient has a 3-per-second spike-wave pattern. This is typical of primary generalized epilepsy. Without a behavioral correlate, one could only speculate as to the type of seizure, however, with there being no motor activity associated with this discharge, absence seizure is the clinical interpretation. Drowsy burst should not have the sharp component and does not grow as this discharge does. Non-epileptic seizure is behavioral symptoms without EEG correlate, different from this presentation. Non-epileptic seizures may have movement artifact, but the appearance and distribution of this discharge indicates that it is electrocerebral.

OIRDA

Figure **8-35** shows the EEG of a child with moderate encephalopathy. He has a history of medulloblastoma status post chemotherapy and radiotherapy. He presents with sepsis and lethargy. A portion of the EEG is shown. This patient has occipital intermittent rhythmic delta activity (OIRDA). This is a counterpart to FIRDA, and is seen mainly in children. The etiology is thought to be a disconnection syndrome between cortical and subcortical centers. The finding is clearly abnormal, but not specific for a single etiology.

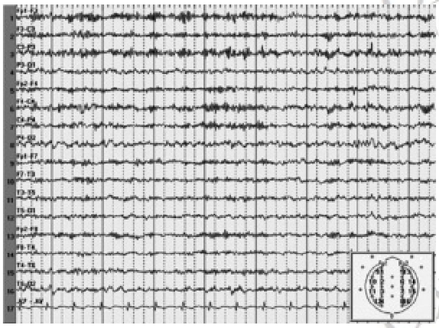


Figure 8-35:

Focal Attenuation in a Patient with Right Hemisphere Stroke

This patient has had a large right hemisphere infarction and subsequently had seizures. EEG (Figure **8-36a**) shows signs of the focal damage while the MRI (Figure **8-36b**)

shows typical signs of acute-subacute infarction. Review of the EEG shows frontal activity that is attenuated over the right hemisphere. However, it would be easy to assume that the left side with the higher amplitude slowing is the more abnormal side.

Figure 8-36:

Surgical Cases

Scenario A: Single Discrete Structural Lesion with Congruous EEG Localization

This is a patient with a single discrete structural lesion with known epileptogenic potential and congruous EEG data—the EEG localization fits the structural lesion location.

This is a 26-year-old left handed/ambidextrous man who had seizure onset at 24 years with complex partial seizures. Seizures are described as hot flash, staring, lip smacking, clenching of the fist. Duration is 15–30 sec. Seizure frequency is about one per week. He had failed gabapentin, oxcarbazepine, oxcarbazepine + levetiracetam combination.

EMU seizure description is of a motionless stare followed by lip smacking and right finger extension movements.

MRI (Figures **8-37a** and **8-37b**) showed a cavernous malformation in the left temporal region seen well on coronal and axial T2 sequences.

Figure 8-37a:

Coronal T2 MRI showing cavernous malformation in the left mesial temporal region.

Figure 8-37b:

Same patient, axial image.

EEG (Figure **8-38a**) showed rhythmic discharge seen best on sphenoidal electrode on the left, indicating inferomesial temporal region discharge. Consecutive EEG page (Figure **8-38b**) shows spread of the seizure activity in the left temporal region to involve T1, F7, and T7. But the discharge maintains predominance at Sp1.

Figure 8-38a:

Seizure onset with an alpha-range rhythmic discharge at Sp1, recording from the left inferomesial temporal region.

Figure 8-38b:

Subsequent page to the previous figure, demonstrating spread of seizure activity in the left temporal region to involve T1, F7, T7. Discharge maintains prominence at Sp1.

Neuropsychological testing: low average intellectual range, consistent with educational attainment and demographic history. Verbal IQ was 80 (9th percentile), and performance IQ was 88 (21st percentile). He had low performance on language skills overall. Testing showed bilateral prefrontal weaknesses with weaknesses in visuospatial processing. Wada test results were left hemisphere dominance for language, bilateral memory (passed memory testing with left and right amobarbital injections).

Stereotactic resection through a transcortical approach was successful. MRI (Figure **8-39**) shows surgical results. He was seizure-free off AEDs at 2.5 years follow-up.

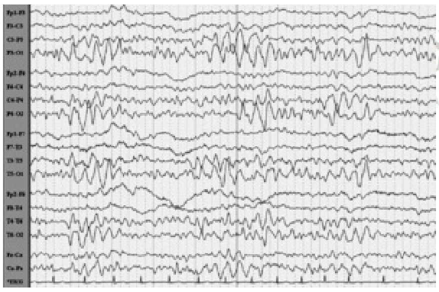


Figure 8-39:

Post-operative changes are seen in the left temporal region on this T2 weighted image.

Scenario B: Single Discrete Structural Lesion with Incongruous EEG Results

This patient has a discrepancy between location of the structural lesion on MRI and the EEG localization. MRI shows a posterior temporal region of abnormality but EEG suggests anterior temporal ictal onset.

A 42-year-old right-handed man presents with seizures since 10 years of age. The seizures are described as feeling like a pop in his head, then stares, smacks lips, repeats the word “what,” and has manual picking automatisms. Seizures last 20 seconds and he has word-finding difficulty after the events. Seizure frequency is about 3 per month. He has failed gabapentin, oxcarbazepine, oxcarbazepine + levetiracetam combination.

EMU seizure description was fumbling with the left hand followed by right arm dystonic posturing of the right arm, lip smacking and chewing, versive head turning and eye deviation to the right in transition to generalization.

MRI (Figures **8-40a** and **8-40b**) showed cavernous malformation in the mid-posterior lateral temporal region.

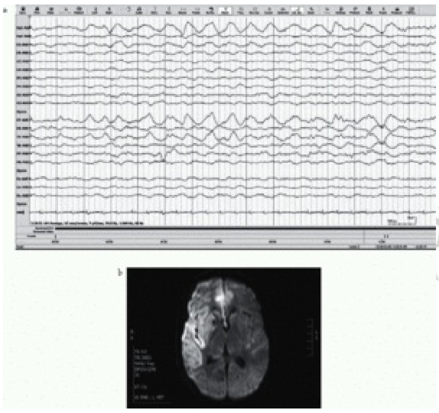


Figure 8-40a:

Left mid-posterior lateral temporal lesion.

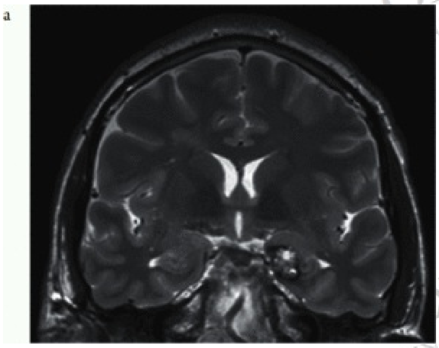


Figure 8-40b:

Left mid-posterior lateral temporal lesion.

EEG (Figures **8-41a** and **8-41b**) shows ictal onset with 7-8 Hz rhythmic activity at Sp1 more than F7 more than T7.

Figure 8-41a:

Ictal onset with rhythmic 7-8 Hz activity starting at Sp1.

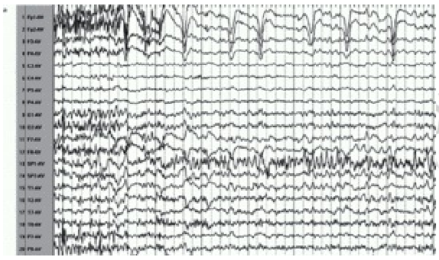


Figure 8-41b:

Another ictal onset example from the same patient showing predominant inferomesial-anterior temporal region discharge, Sp1 > F7 > T7.

Interictal activity was prominent in the left inferomesial temporal region, Sp1 more than F7, and posterior temporal region, P7 more than T7 (Figure **8-41c**).

Figure 8-41c:

Same patient, interactivity in the left inferomesial temporal region (Sp1 > F7) and posterior temporal region (F7 > T7).

Neuropsychological testing showed borderline abilities, significantly stronger aptitude for nonverbal than verbal skills, and stronger memory from visual material than verbal material.

Wada test results were left hemisphere dominance for language, bilateral memory (passed memory testing with left and right amobarbital injections).

The cavernous malformation was resected and the surgical result is shown in the MRI (Figure **8-42**). Clinical outcome was excellent with the patient free of complex seizures at 7 years follow-up, but he still has isolated auras.

Figure 8-42:

Sagittal T1-weighted MRI showing successful resection of the malformation with good clinical result.

Scenario C: Right TLE with Right Hippocampal Sclerosis

This is a case of right temporal lobe epilepsy with right hippocampal sclerosis.

She was a 49-year-old woman with epilepsy since the age of 15 years but was only diagnosed at 32 years. The seizures had been attributed to head trauma with loss of consciousness at age 1 year.

She had both simple partial and complex partial seizures. The simple partial seizures started with a feeling of tingling starting around the abdomen and rising to the neck and head. She also had a taste in her mouth.

She also had complex partial seizures described as 80% preceded by an aura progressing to spacing out, lip smacking, extremity automatisms (ex: swinging of the right foot), and verbal automatisms (may pray out loud). Duration is usually less than 30 sec, followed by few minutes of postictal confusion.

EMU recorded seizures that were described as a funny feeling of flushing and shakiness, with a brief motionless stare and fluent speech. Simple partial seizures were about one per day, complex partial seizures were once every two days.

Treatment had been with lamotrigine up to 700 mg/day and levetiracetam up to 3000 mg/day. She had failed phenytoin, valproate, carbamazepine, lamotrigine monotherapy and combinations.

EEG (Figure **8-43a**) showed ictal onset in the right temporal region with right inferomesial temporal predominance, most prominent at Sp2 with lesser demonstration at F8 and T8.

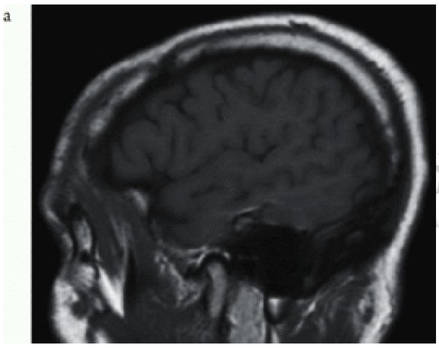


Figure 8-43a:

Ictal onset discharge was in the right temporal region with right inferomesial temporal predominance, Sp2 > F8 > T8.

Interictal EEG (Figure **8-43b**) shows discharge in the right temporal region with right inferomesial temporal predominance.

Figure 8-43b:

Interictal EEG shows discharge in the right temporal region with right inferomesial temporal predominance.

In addition to the interictal discharge was irregular slow activity in the right temporal region (Figure **8-43c**).

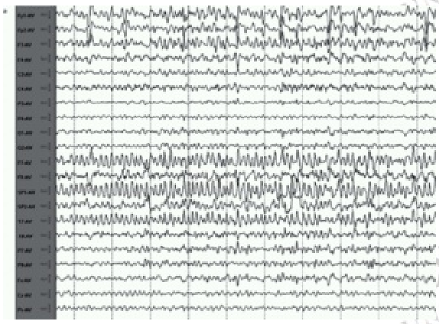


Figure 8-43c:

Interictal activity included irregular slow activity in the right temporal region.

MRI brain (Figure **8-44a**) showed marked atrophy of the right hippocampus.

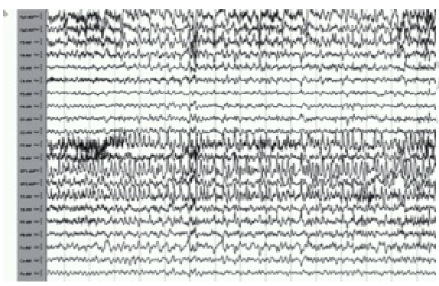


Figure 8-44a:

MRI brain showed marked atrophy of the right hippocampus.

FDG-PET (Figure **8-44b**) showed decreased FDG uptake in the right mesial temporal region, as note in the figure by arrows.

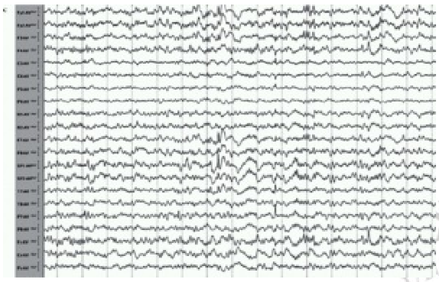


Figure 8-44b:

FDG-PET showed decreased FDG uptake in the right mesial temporal region (arrows).

Right transcortical selective amygdalohippocampectomy was performed with good surgical result, as shown on MRI (Figure **8-44c**).

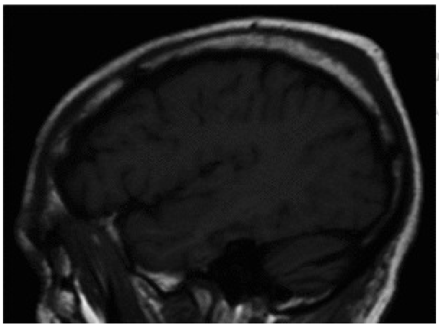


Figure 8-44c:

Right transcortical selective amygdalohippocampectomy was performed with good surgical result as shown on MRI.

Clinical outcome was excellent with patient free of complex partial seizures and auras at 6 years of follow-up. She had two complex partial seizures and several isolated auras during lamotrigine taper, but these came under control as the dose was increased.

Scenario D: TLE with Left Hippocampal Sclerosis

This is a case of a patient with left temporal lobe epilepsy due to hippocampal sclerosis.

The patient was a 39-year-old right-handed woman with epilepsy since age 10 years. She had an antecedent complex febrile seizure at age 18 months.

She had both simple partial and complex partial seizures. The simple partial seizures started with a feeling that is hard to explain. She used to have tingling on the left side.

Complex partial seizures usually had no aura; seizures mostly started with loss of awareness, a deep stare, and automatisms including rubbing of the legs and smacking of the lips.

EMU recording showed seizures characterized by motionless staring, early head turning to the left, right arm dystonic posturing, automatisms of the left arm, occasional oro-alimentary automatisms, and postictal aphasia. She also had versive head deviation to the right in transition to secondary generalization.

Frequency of the simple partial seizures was once every 2–3 days, frequency of the complex partial seizures was one every 1.5 weeks. Secondary generalized seizures were rare, with the last one more than a year prior to evaluation.

She was on carbamazepine, zonisamide, and pregabalin. She had failed phenytoin, phenobarbital, primidone, valproate, gabapentin, levetiracetam, topiramate, lamotrigine, and clonazepam.

EEG (Figure **8-45a**) showed ictal discharge in the left temporal region with left inferomesial temporal predominance. The ictal field widened during the course.

Figure 8-45a:

Interictal activity was sharp waves in the left temporal region with greatest prominence in the region of Sp1 and lesser in F7 and T7 (Figure **8-45b**).

Figure 8-45b:

MRI brain (Figure **8-46a**) showed atrophy and increased T2 signal in the left hippocampus.

Figure 8-46a:

FDG-PET (Figure **8-46b**) showed left temporal hypometabolism, greatest in the left mesial-basal temporal region.

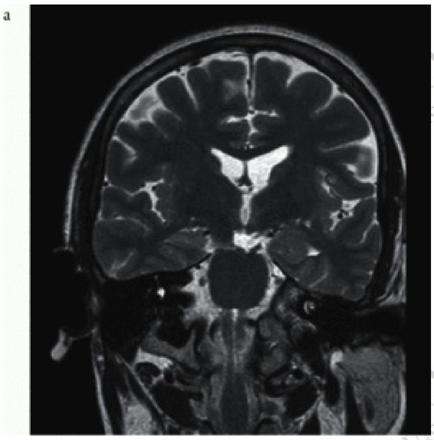


Figure 8-46b:

Operative result was excellent. MRI (Figure **8-46c**) showed the region of the transcortical left selective amygdalohippocampectomy. Patient was free of complex partial seizures and auras at 5 years of follow-up. She had one complex partial seizure during carbamazepine withdrawal, but there was no recurrence after the dose was increased.

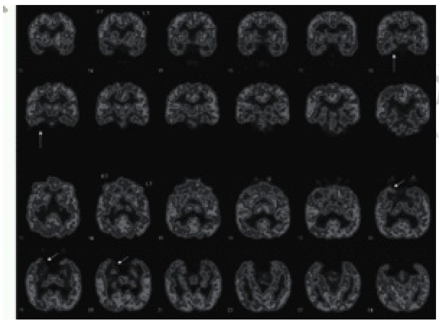


Figure 8-46c:

Scenario E: Temporal Lobe Epilepsy Without a Defined Structural Lesion

This is a 25-year-old right-handed woman with epilepsy since age 5 years.

She had complex partial seizures described as having no warning, characterized by gagging, picking with right arm, able to speak in sentences although usually

inappropriate. Afterward has brief confusion without focal postictal deficits. Has no recollection of these events. Duration less than 1 minute.

EMU recorded seizures showed key features including bilateral paddling movement of the lower extremities and left gaze deviation, along with arrhythmic arm shaking and a motionless stare. May have well-formed verbal automatisms (would say "I am fine, I am fine").

Seizure frequency for complex partial seizures was about 6 per month; secondarily generalized seizures had only occurred twice in her life.. Medical therapy at the time of presentation was levetiracetam, topiramate, and pregabalin. She had previously failed valproate and gabapentin.

Interictal EEG (Figure **8-47a**) shows sharp waves in the right frontotemporal region, greatest around F8 and Fp2 and less at T8 and P8.

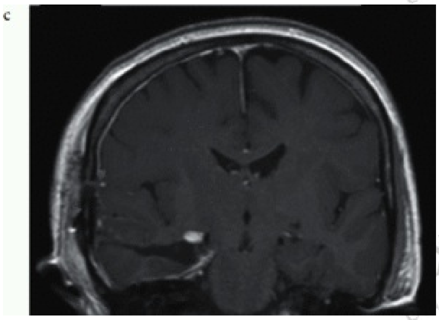


Figure 8-47a:

Interictal sharp waves are right frontotemporal, F8, Fp2 > T8 > P8. There is irregular slow activity in the same distribution.

EEG at ictal onset (Figure **8-47b**) is characterized by voltage attenuation immediately after a high voltage sharp wave that resembles interictal sharp waves.

Figure 8-47b:

EEG at ictal onset is characterized by voltage attenuation immediately after a high voltage sharp wave that resembles interictal sharp waves.

MRI brain (Figure **8-48a**) showed no lesion, particularly no hippocampal atrophy.

Figure 8-48a:

MRI brain showed no lesion, particularly no hippocampal atrophy.

FDG-PET (Figure **8-48b**) showed no asymmetry.

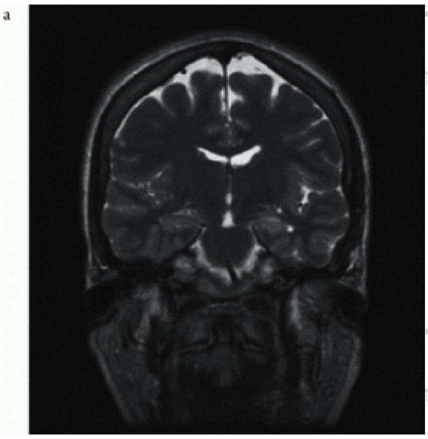


Figure 8-48b:

FDG-PET showed no asymmetry.

Ictal SPECT (Figure **8-48c**) showed right lateral temporal increased blood flow, different from the interictal baseline (arrow on image).

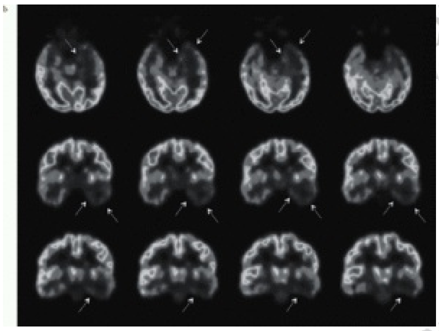


Figure 8-48c:

Ictal SPECT showed right lateral temporal increased blood flow, different from the interictal baseline.

Magnetoencephalography (MEG) (Figure **8-48d**) showed epileptiform activity sources centered predominantly over the mid-posterior lateral temporal region.

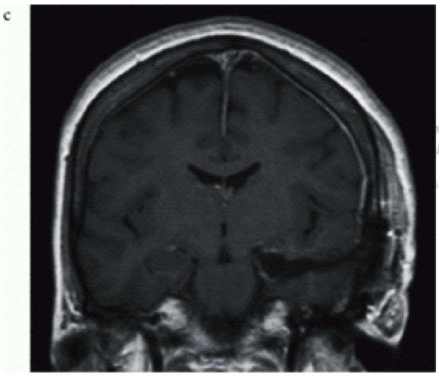


Figure 8-48d:

Magnetoencephalography (MEG) showed epileptiform activity sources centered predominantly over the mid-posterior lateral temporal region.

Wada test showed good memory with injection of either side.

Subdural grid electrodes showed a defined field of the ictal discharge. In Figure **8-48e**, the black circle shows the ictal center, whereas the white line surrounds the next most affected electrodes.

Figure 8-48e:

Subdural grid electrodes showed a defined field of the ictal discharge. In the figure, the black circle shows the ictal center whereas the white line surrounds the next most affected electrodes.

Right temporal lobectomy was performed with good surgical results (Figure **8-48f**).

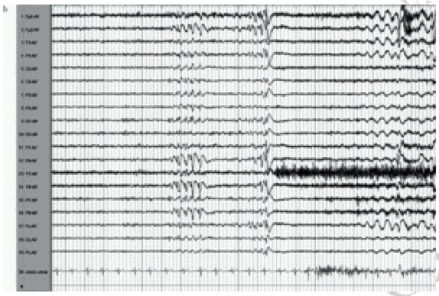


Figure 8-48f:
Sagittal T1.

Right temporal lobectomy was performed with good surgical results.

Clinical outcome was excellent with her free of complex partial seizures at 5 years follow-up. She remains on seizure medications, not being willing to take the risk of seizure recurrence with AED withdrawal.

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Appendix: References and Glossary

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Glossary

14 & 6 positive spikes:
Positive spikes mainly in the posterior temporal region, especially in drowsiness and light sleep. Considered normal if there are no other abnormalities.
Absence:
Seizure characterized by a brief lapse of consciousness without major motor activity. Associated with the 3-per-second spike-wave complex.
Alpha rhythm:
EEG rhythm in the frequency range of 8–13 Hz. normal when a posterior rhythm in a waking state. Abnormal when seen anteriorly in a coma.
Amplifier:
Electronic device that increases the amplitude of an electronic signal. Usually composed of transistors as well as other circuit elements

Analog:
Data as a continuously variable value, as opposed to digital.
Analog-to-digital converter:
Electronic device that converts an analog signal (continuously variable voltage) into a digital signal (sequence of data bits representing the data).
Arrhythmic:
Term used to describe ongoing EEG activity composed of waves of unequal duration.
Asynchronous:
Describes transients or other activity that is seen in several regions, but not simultaneously.
Atonic:
Loss of tone. Atonic seizures are associated with loss of tone rather than muscle contraction.
Aura:
Subjective sensation that precedes a seizure.
Benign epilepsy with centrotemporal spikes (BECTS):
Another term for Rolandic epilepsy.
Beta rhythm:
EEG rhythm greater than 13 Hz. Appears in normal studies, but especially with some sedatives including benzodiazepines.
Brain death:
Irreversible loss of brain function that in most jurisdictions is equivalent to death in a legal sense.
Breach rhythm:
Increase in amplitude and frequency of EEG activity over a skull defect. Due to loss of some of the attenuation due to skull, which generally is not a good electrical conductor.
Burst suppression pattern:
Episodic bursts of activity interspersed with longer episodes of suppression.
Capacitance:
Ability of an electric system to store energy by separation of charge. Capacitance exists not only in capacitors as individual circuit elements but also between other conducting elements of a circuit.
Capacitor:
Circuit element that stores energy in the form of separation of charge. Composed of adjacent conducting materials
Circuit:
Closed path of circuit elements to achieve some electrical task.
Circuit element:
One of a number of devices that are used to create circuits. Includes resistors, capacitors, diodes, transistors, inductors, and others.
Circuit loop:
One closed loop of a circuit, ignoring the other potential connections and loops in the circuit.
Clonic:
Series of phasic contractions, usually producing shaking.
Complex:
Combination of 2 or more waves.
Complex partial seizure:
Partial (focal) seizure which is associated with loss of awareness. As opposed to simple partial seizure.
Conductance:
Quality of a material to conduct charge. In the case of electricity, it represents the ability of the material to allow the flow of electrons. In the case of biologic membranes, conductance indicated by the ability of ions to pass through the membrane.
Conductor:
Material that easily conducts current by allowing the flow of electrons. This requires atomic structure to mobilization of electrons.
Cone wave:
High voltage occipital cone-shaped waves, in infants.
Current:
Movement of electrons in a circuit. By convention, direction of current is in the flow of positive charge, but since current is carried by negatively charged electrons, current direction is opposite to the flow of electrons.
Delta rhythm:
EEG rhythm of less than 4 Hz. Seen normally in sleep but can also be seen with encephalopathy, focal structural lesion, and in children.
Digital:
Data as an array of digits, regardless of base. While we display data in base 10, computers fundamentally operate in base 2, with combinations to create longer digital words.
Diode:
Device made by layering two pieces of semiconductor. Conducts in one direction.
Discharge:
Electrical potential burst recorded on EEG.
Dravet syndrome:
Eponymic name for severe myoclonic epilepsy of infancy.
Epileptic seizure:
Episode of change in neurologic behavior due to abnormal neuronal activity in the brain.
Epilepsy:
Recurrent episodes of seizure activity typically associated with abnormal EEG rhythms.
Epileptiform discharge:
Episodic waves or complexes that stand out from the background and suggest a predisposition to epilepsy.
Fast alpha variant:
Posterior rhythm that is 16–20 Hz rather than 8.5–10 Hz, essentially a harmonic of the normal posterior dominant rhythm.
Frequency:
The number of waves of a specified rhythm per second, or 1/wavelength. Frequency is measured in Hertz or Hz, meaning cycles per second. Wavelength is measured in milliseconds or seconds.
Frontal intermittent rhythmic delta activity (FIRDA):
Rhythmic delta from the anterior regions, especially in patients with diffuse or metabolic disorders.
Ictal discharge:
EEG discharge that is associated with a seizure.
Impedance:

Measure of the effective resistance of a circuit where voltages are changing. While typically used to describe AC circuits, it also applies to other changing voltages. Due to resistance of the elements plus effects of inductance and capacitance on current flow.
Inductance:
Measure of the induction capacity of an inductor.
Induction:
Production of current in a conductor by a changing magnetic field.
Inductor:
Circuit element composed of a wire winding so that the magnetic fields from movement of current flow sum to form larger magnetic field.
Interictal:
Between seizures. Used to describe a pattern on EEG that is seen between clinical seizures.
Interictal discharge:
EEG discharge that is seen in patients with seizures, yet the discharge it not, itself, a seizure.
Irregular rhythm:
Activity that is not uniform. It is in theory possible for rhythmic activity to be irregular, but that is uncommon.
K-complex:
Fusion of a vertex wave with a sleep spindle. Seen mainly in stage 2 sleep and with partial arousal.
Kirchhoff's current law:
For any node, the sum of the currents flowing into the node is equal to the currents flowing out.
Kirchhoff's voltage law:
For any resistive circuit loop, the sum of the voltage sources is equal to the sum of voltage drops.
Lambda wave:
Occipital positive waves created by visual exploration.
Lennox-Gastaut syndrome:
Severe epilepsy with mixed seizures.
Mitten:
EEG potential formed from partial fusion of a vertex wave and spindle wave. The thumb of the mitten is a spindle wave and the hand is the vertex wave.
Mu rhythm:
Normal negative rhythmic potentials.
Myoclonic:
Sudden positive or negative motor symptoms, such as a brief jerk of a muscle.
Narcolepsy:
Disorder of recurrent attacks of daytime sleep attacks, often also with episodes of paralysis (cataplexy).
Non-conductor:
Material that does not conduct current. Has atomic structure that does not allow for free flow of electrons from atom to atom.
Notch filter:
Archaic term for a 60 Hz filter—refers to a “notch” seen in the power spectrum produced by the filter.
Obstructive sleep apnea:
Disorder that produces periods of apnea because of failure to maintain a patent airway when asleep
Occipital intermittent rhythmic delta activity (OIRDA):
Abnormal episodic delta activity seen especially in children from the posterior regions. Usually seen with diffuse and metabolic conditions. Childhood correlate of FIRDA.
Ohm's law:
For any resistive circuit, current is positively correlated with voltage and negatively correlated with resistance. Or voltage is equal to current times resistance.
Open time:
The time that an ion channel stays open after being activated. Ion channels generally close after a brief time, regardless of what happens to the membrane potential.
Periodic:
Term used to describe transients or complexes that recur, but with intervening activity between them.
Periodic lateral epileptiform discharges (PLEDs):
Discharges from one hemisphere or locus at a rhythm that is often about 1/sec. Seen especially with destructive lesions.
Photoconvulsive response:
Electrical seizure activity produced by photic stimulation.
Photoelectric artifact:
Artifact seen during photic stimulation where the electrodes are directly activated by the light flashes.
Photomyoclonic response:
Electrical manifestation of an involuntary contraction of frontal muscles during photic stimulation.
Positive sharp transients of sleep (POSTS):
Positive potential with a maximum at O1 and O2, seen during light sleep.
Posterior dominant rhythm:
Rhythm from the occipital region that is composed of a narrow band of a dominant frequency, usually in the alpha range in adults.
Posterior slow wave of youth:
Slow waves in the occipital region in waking state, mainly of young children.
Postictal:
Referring to the time after a seizure, such as postictal EEG appearance or clinical state.
Power:
A measure of the ability to do work, for example, the energy of a power supply or of brain electrical activity.
Power spectrum:
Distribution of energy across different frequent components.
Power supply:
Circuit element that imparts energy to electrons, causing them to move down a potential gradient.
Primary generalized seizure:
Seizure that is generalized from the onset, as opposed to secondarily generalized seizure.
Psychogenic non-epileptic seizure:
Episodic neurologic events that can resemble epileptic seizures but that are due to psychological issues rather than due to a change in neuronal activity in the brain.
Rectifier:
Device that converts AC into DC current.
Rectify:
Convert AC into DC current. Most modern circuits may use AC line power but many of the electronics are powered by DC.
Regular rhythm:

Applies to activity that is uniform, with individual waves having fairly consistent shape, in addition to fairly consistent duration.
Resistance:
The degree to which a material opposes the passage of electric current. Dissipates the energy in another form, usually heat.
Resistor:
Circuit element that opposes the passage of current, dissipates the energy usually in the form of heat.
Rhythm:
EEG activity composed of recurring waves of equal duration. A rhythm is often characterized by its frequency.
Rhythmic:
Term used to describe ongoing EEG activity composed of recurring waves of equal duration.
Rhythmic midtemporal theta of drowsiness:
Trains of charply-contoured waves in the theta range from the temporal region in the drowsy state.
Rolandic epilepsy:
Disorder of children with epilepsy with a focus in the centro-temporal region.
Secondarily generalized seizure:
Generalized seizure that has a focal onset.
Seizure:
Sudden attack that is usually due to abnormal rhythmic discharge of neurons.
Semiconductor:
Material that has conductivity better than a non-conductor but less than a conductor. A key element to diodes and transistors.
Semiology:
Study of signs of seizures.
Sharp wave:
Transient with a duration of 70–200 mg that is often epileptiform, although some sharp waves are normal or if abnormal are not epileptiform. Must stand out from the background; not every wave of this window of duration is a sharp wave.
Sharply contoured slow wave:
Transient that has a duration longer than a sharp wave but has a subjectively sharp appearance and stands out from the background.
Simple partial seizure:
Partial (focal) seizure with no disturbance of consciousness, as opposed to complex partial seizure.
Sleep spindle:
Brief run of repetitive waves in the 11–14 Hz range. Are usually of 1–2 sec duration. Seen in light sleep.
Slow alpha variant:
Posterior alpha rhythm in waking state which is a sub-harmonic of the normal posterior alpha.
Spatial distribution.
The electrodes involved with a discharge and the degree of their involvement determines the field.
Spike:
Transient with a duration of 25–70 mg that is often epileptiform. Not all spikes are epileptiform, and some are normal. Spikes must stand out from the background to be interpreted. Not all potentials with this duration are spikes.
Spike-wave complex:
Spike followed by a slow wave.
Startle:
Jerking body movements due to a stimulus.
Stevens-Johnson syndrome:
Skin and mucous membrane necrosis that can develop from some medications.
Synchronous:
Occurring in two regions simultaneously.
Syncope:
Loss of consciousness due to insufficient cerebral blood flow.
Theta rhythm:
EEG rhythm in the 4–7 Hz range. Normal in drowsiness at all ages and waking in young children. Also seen in encephalopathy, focal structural lesion.
Third rhythm:
Rhythmic temporal activity in the waking state. Normal.
Tonic:
Increase in tone, in context of a seizure, steady contraction.
Transient:
A wave or combination of waves that stands out from the surrounding background.
Transistor:
Semiconductor device that is able to amplify or rectify electrical current.
Vertex wave:
Negative potential with a maximum near Cz. Occurs in stage 2 sleep and during arousal.
Voltage:
Potential difference that is an electromotive force for circuits.
Voltage drop:
Reduction in voltage across a resistor or other circuit element. This indicates the reduction in energy associated with the electrons across this element.
Voltage-gated:
Voltage-gated ion channels open in response to a change in transmembrane voltage of the cell.
West syndrome:
Infantile spasms plus mental retardation.
Wicket spikes:
Sharply contoured waves from the temporal region during drowsiness and light sleep.

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